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MOIRS OF THE GEOLOGICAL SURVEY.

ECIAL REPORTS ON THE MINERAL RESOURCES OF GREAT BRITAIN.

ENGI STORAGE

VOL. XII.—IRON ORES (*contd.*).—BEDDED ORES OF THE LIAS, OOLITES AND LATER FORMATIONS IN ENGLAND.

By G. W. LAMPLUGH, F.R.S., C. B. WEDD, B.A., AND J. PRINGLE.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

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W. LAMPLUGH, F.R.S., C. B. WEDD, B.A.,
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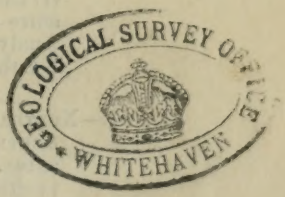

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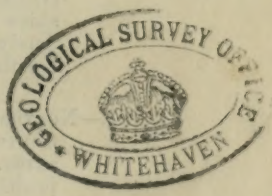

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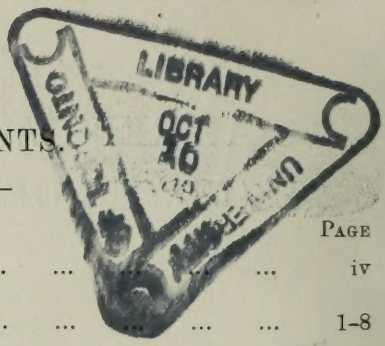

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PREFACE BY THE DIRECTOR.

This volume, the fifth of the 'Special Reports' to be devoted to an account of iron-ores, deals with some of the most important of our home-resources. The strata that carry the ore occur as members of a series of sedimentary deposits, and, as such, are distinct from the veins and other ore-bodies described in previous volumes. They are found in formations ranging in age from the Lias upwards, and though the ore is mostly of low grade, it is abundant and much of it accessible either by quarrying or shallow mining.

In Cleveland, opencast working has been almost replaced by mining. The Midland iron-fields include a visible outcrop and an adjacent area thinly covered by newer formations, but capable of being worked in the open. In addition there exists in several cases an underground extension, which is more deeply buried and the value of which remains to be ascertained, the productiveness being dependent upon such factors as persistence of the ore-bed as regards thickness and composition, and the cost of mining as compared with that of open quarrying.

Persistence in composition especially calls for consideration. The ores in every case have been formed wholly or partly by the replacement of carbonate of lime by an iron-compound, though whether that replacement was 'contemporaneous,' that is, effected before the succeeding strata were laid down, or took place subsequently, is a debatable question. However this may have been, it is a fact that the replacement has come into operation sporadically. The Marlstone, for example, is workable as an ore in Cleveland, Lincolnshire, Oxfordshire and some adjacent counties, but has not been sufficiently enriched to be worth raising in intervening parts of its outcrop. The Corallian and Cretaceous ores are no less sporadic in their developments. It may be supposed that enrichment, when of a subsequent age, was determined by local conditions, such as the character of the associated strata, geological structure and the circulation of underground water. The necessary conditions existed in various districts from Raasay to Lorraine, and recurred at several episodes of Mesozoic times, but that they were strictly local in their effects must be borne in mind in estimating the reserves of our concealed Mesozoic iron-fields.

Another alteration, certainly of subsequent age, consists in the enrichment of an ore-bed by weathering. From that part of it which has been exposed at the surface by denudation, enrichment has taken place mainly by the removal of carbonate of lime in solution, whereby the percentage of iron has been increased. In some districts profitable working is confined to the areas in which this enrichment has taken place.

An estimate of reserves of the bedded Mesozoic ores falls under the same two heads as that for reserves of coal, namely areas which have been proved, and areas in which the existence of ore is regarded as probable on geological evidence. An estimate published in the 'Summary of Progress for 1917.' 1918, p. 7, accordingly gives the figures for Mesozoic ores under the two titles "Reserves more or less developed" and "Probable additional Reserves." The present volume contains the evidence on which those figures are founded.

It must be remembered, however, that a rock containing sufficient iron to be worth working under the existing conditions of demand and supply may not be worth working under other circumstances. The Coal Measure ores for example at one time formed a principal source of British iron but are now almost neglected in favour of the Mesozoic ores. The value of reserves therefore depends partly upon the fluctuating relations of demand and supply.

The field-work required for the investigation of Mesozoic ores was done in 1917 by Mr. Lamplugh, Mr. Wedd and Mr. Pringle, under the superintendence of the first-named. Mr. Lamplugh himself furnishes an account of the Cleveland district and of some minor occurrences of historic interest. The description of the ores of Lincolnshire, Leicester, Rutland and Northamptonshire has been written by Mr. Wedd, and is continued through Northamptonshire and Oxfordshire by Mr. Pringle, who also deals with the ores of Wiltshire and Dorset.

We have to make acknowledgment of the unfailing courtesy with which we have been met by the numerous firms whom it was necessary to approach. In all cases free access was given to workings and plans, and frequently personal assistance was rendered. Much statistical information had already been supplied to the Ministry of Munitions, and of this we have been courteously permitted to make full use. The list of firms and individuals to whom we are indebted is too lengthy for insertion here; acknowledgments are made in the appropriate places in the text.

A. Strahan.
Director.

Geological Survey Office, 28, Jermyn Street,
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19*th March*, 1919.

BEDDED IRON ORES OF THE LIAS, OOLITES AND LATER FORMATIONS IN ENGLAND.

CHAPTER I.

GENERAL INTRODUCTION.

By G. W. Lamplugh.

The ironstones occurring as bedded deposits among the newer rocks of this country have been utilised from prehistoric times, but it was not until nearly the middle of last century that they sprang into importance as a source of iron on a large scale. Since then, their economic consequence has steadily increased, so that now they supply by far the greater part of the iron obtained from our native ores.

The ores are all of low grade, most of them ranging in the neighbourhood of 30 per cent. in their iron content, few rising to 40 per cent. and some falling as low as 20 per cent.

The value of a rock as an iron-ore, however, does not depend solely upon its percentage of iron, but upon its general composition and behaviour when smelted. Thus, a rock containing much silica and little or no lime, along with a certain proportion of iron, may be rejected under present practice as worthless, on account of its refractoriness, while a rock containing less silica and much lime, along with the same proportion of iron, may be a valuable smelting ore. The proportion of the minor constituents, particularly of the manganese, phosphorus and sulphur, is likewise of great practical consequence. Hence, a rock containing 20 to 24 per cent. iron may be a detrimental 'shale,' to be carefully separated from the 'ore,' or it may be a 'good stone,' to be passed through the smelter. Moreover, with changes and improvements in the systems of smelting, a rock that has been valueless for one method may become valuable for another. Therefore no sharp division can be drawn between the ferruginous rocks that are to be accounted as ores and those that are not. Few rocks are entirely free from iron, and in many shales and ferruginous limestones and sandstones, such as occur in thick masses in the Lias and Oolites, the percentage of metallic iron ranges often between 5 and 10 per cent. Even from such rocks it would be practicable to extract iron, though not profitable, so long as richer material is available. At present about 20 per cent. appears to be the lowest limit for a smeltable stone combining all the desirable qualities, and about 26 per cent. for a stone in which the elements are less favourably mixed. No stone of lower content than 20 per cent. has been included in the estimates of reserves given subsequently in this memoir.

Ironstones recognised as of ore-quality occur at one place or another in nearly every geological division of the stratified rocks, but in most cases as thin seams or discontinuous nodules which could not be profitably extracted. More rarely, however, the seams of iron-bearing rock are many feet in thickness and extend over

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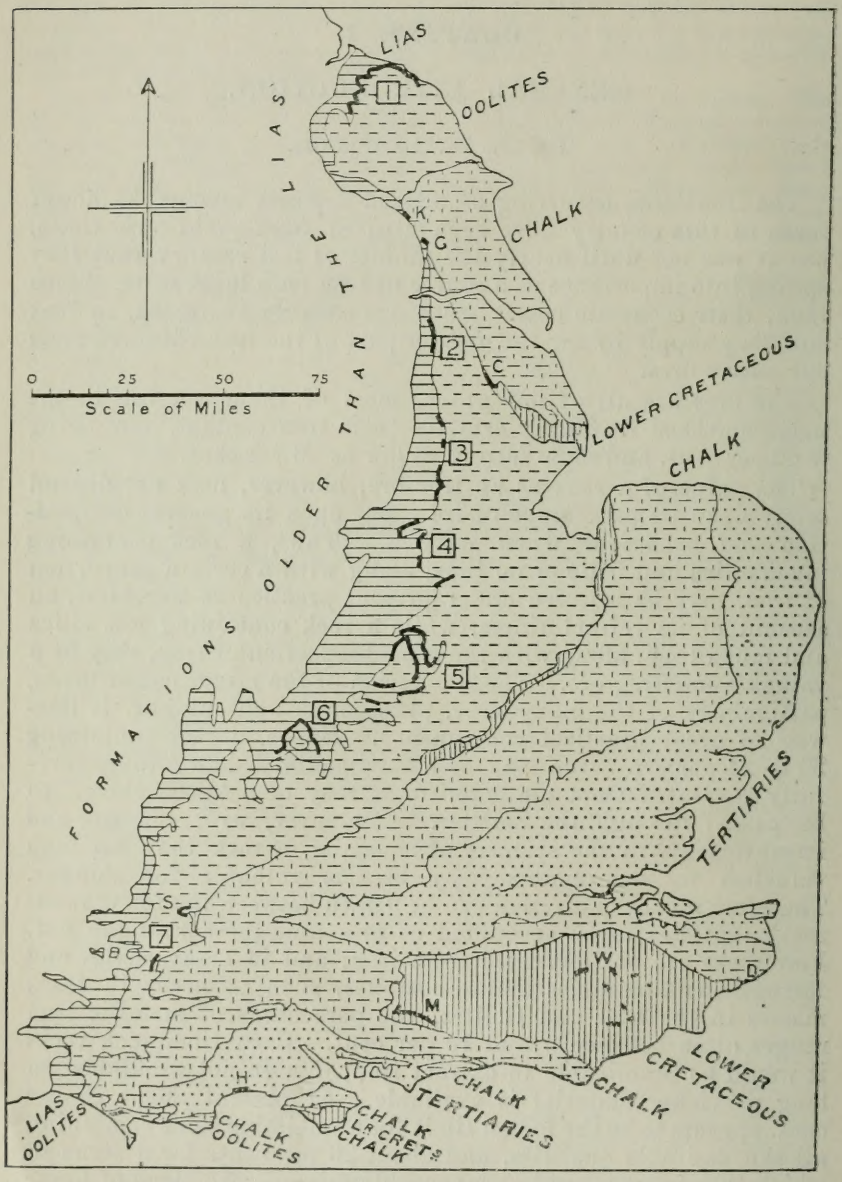
FIG. 1.—*Sketch-map showing the position of Ironstones in the Lias, Oolites and later formations in England.*



EXPLANATION.

DISTRICTS.

1. Cleveland.
2. Frodingham.
3. Mid-Lincolnshire.
4. Leicestershire, etc.
5. Northamptonshire.
6. Oxfordshire.
7. Westbury.

MINOR LOCALITIES.

K. Kirby Underdale.
G. Goodmanham.
C. Claxby.
S. Seend.
A. Abbotsbury.
H. Hengistbury Head.
M. Midhurst.
W. The Weald.
D. Dover.

many square miles, and they then become of great practical value. It is from seams of this kind that the great iron-fields of Cleveland, North Lincolnshire, Leicestershire, etc., Northamptonshire and Oxfordshire draw their supplies.

The following Table of English Formations (p. 4) newer than the Trias, in which the principal occurrences of iron-ore are indicated, will serve to show the relative stratigraphical position of the deposits described in the succeeding chapters.

The sketch-map, Fig. 1, shows the general arrangement of the formations and the position of the ironstone districts.

It will be seen that, at present, the Lias and the Lower Oolites are the formations from which nearly all the English supplies of ore from the Secondary rocks are drawn. The other formations from which ores are or have lately been extracted are the Corallian and the Lower Cretaceous, both of which are likely to be worked further in the future. The deposits in the other formations are probably all negligible from the economic point of view, except that small quantities of ore might occasionally be gleaned from them during excavation for other purposes.

Lower Lias.

The predominant components of the Lower Lias throughout England are sandy shales and impure flaggy limestones, generally somewhat ferruginous but rarely rich enough to be used as ore. In North Lincolnshire, however, a portion of the series becomes greatly enriched and makes a valuable ore which is worked on a large scale, constituting the old established and prosperous Frodingham district, described in chapter iv. This ore-field extends for about 7 miles from north to south, terminating northward before reaching the Humber, and southward in the country between Frodingham and Gainsborough; but in the same belt farther southward the beds (usually impure limestones) show a tendency toward the ferruginous condition, and have been tried in some parts as ores (*see* p. 72). Thin ferruginous bands and ironstone nodules are of common occurrence in other places, particularly in the upper part of the series in Gloucestershire (*see* 'Jurassic Rocks,' vol. iii, pp. 302-3) where the nodule-beds were at one time worked.

Middle Lias.

The Middle Lias is the richest in iron-ore of all the English Secondary formations, and is generally in part ferruginous even in the districts where its iron is not sufficiently concentrated to form an ore. It carries the great ironstone fields of Cleveland (chap. ii), East Leicestershire with Mid Lincolnshire, etc., and Oxfordshire, etc. (chap. v): but the similar deposit of Raasay in Scotland has now been proved to fall within the Upper Lias. (*See* 'Special Reports,' vol. xi, 'The Iron Ores of Scotland'). The workable deposits in England are confined to the upper portion of the formation, known in the Midlands as the 'Marlstone' or 'rock-bed,' which in different parts of its course varies from an oolitic

Table of Formations.

	Name of Formation.	*General Composition.*	*Iron.*
	Recent and Pleistocene.	Superficial clay, peat, gravel, boulder-clay, etc.	None of economic value except a little 'bog-iron.'
Tertiary ...	Pliocene ...	Sand, gravel, shelly beds, silt, clay, etc.	Some ferruginous nodules and patches of 'iron-pan,' none of economic value.
	Oligocene ...	Sand, gravel, clay, etc.	Ferruginous nodules and patches only. Formerly worked slightly at Hengistbury Head (*see* p. 229).
	Eocene ...	Clay, sand, pebble-beds, etc.	None of economic value; some iron-pyrites.
Secondary. — Upper Cretaceous	Chalk	Chalk	None.
	Upper Greensand and Gault	Calcareous sandstone, marl and clay	Some thin ferruginous bands (*see* p. 208); some iron pyrites.
Lower Cretaceous ..	Lower Greensand and Wealden	Sand and sandstone, clay, limestone, marlstone, etc.	Ferruginous sands and marlstone rather abundant (pp. 208-228). Formerly worked in Lincolnshire (p. 210) and Wiltshire (p. 220); also nodular ironstone in the Weald (p. 226).
Upper Oolites	Purbeck Beds	Clay, shale, limestone, etc., with gypsum	None of economic value.
	Portland Beds	Sand and sandstone, limestone, etc.	Do.
	Kimmeridge Clay.	Clay, shale, and thin limestones	None, unless Abbotsbury ore be classed in this formation (*see* p. 221).
Middle Oolites	Corallian Beds	Limestones, marls, and clays	Sometimes ferruginous; ores of Westbury, (p. 216), Abbotsbury (p. 221), and Kent (p. 223).
	Oxford Clay .	Clay	None.
	Kellaways Rock	Sandstone, more or less ferruginous	Doubtful if of any value: East Yorkshire (p. 34). Kent (p. 225).
Lower Oolites	Great Oolite Series	Limestones, sandstones and clays	Some thin ironstone bands not now worked (p. 210).
	Inferior Oolite Series	Do. do.	'Top Seam' of Cleveland (p. 25). Ores of Northamptonshire, etc. (chap. vi).
Lias ...	Upper Lias ...	Clay-shales and thin limestone	Nodules only; no economic value.
	Middle Lias ...	Shale, marlstone and ironstone	Ores of Cleveland (chap. ii), Leicestershire, South Lincolnshire, Midlands and Oxfordshire (chap. v).
	Lower Lias ...	Shale, limestone and ironstone	Ores of North Lincolnshire (chap. iv).

ironstone largely composed of ferrous carbonate to a ferruginous limestone or to a calcareous sandstone comparatively poor in iron. The lower part of the division is usually composed of sandy shales devoid of workable ore.

In Cleveland the principal ore-bed, known as the Main Seam, occurs at, or close to, the top of the division. In its unweathered state this bed consists largely of ferrous carbonate, occurring both as distinct globules or 'oolite grains' and as a fine-grained matrix in which the globules are embedded. It extends from west to east right across the field, but splits and deteriorates in a few miles when traced southward (*see* Figs. 2 and 3, pp. 15, 16). It ranges in thickness from about eleven feet in the north to under six feet in the south of the worked area, and yields at present practically the whole of the iron-ore raised in Cleveland. There are at least three thin lower seams of ironstone in the Middle Lias of the district, but comparatively little work has been done on them, and it is doubtful whether they will ever pay for extraction on a large scale (*see* chap. ii, pp. 19-25).

In South Yorkshire and North Lincolnshire the Middle Lias does not carry sufficient iron to be worth working, but in part of the Midland district it again becomes an important source of supply. Here the upper portion of the subdivision known as the 'Marlstone' usually takes the form of a ferruginous limestone carrying 20 per cent. or under of iron, which is hardly rich enough to be utilised as an ore in its unweathered condition, but becomes a good oxidised ore where exposed at the surface, owing to the removal of most of the lime by the solvent action of percolating water and the concentration of the iron. As the ferruginous rock is more resistant than the shales which normally occur above and below it, small plateaux capped by this band are frequently developed by the process of weathering, so that although the rock is comparatively thin (sometimes under 10 feet and rarely over 20 feet), there is in many places a broad bare outcrop of it which has been converted into ore, with an iron content ranging from 30 per cent. (or a little under) to nearly 40 per cent. An area of this kind forms the East Leicestershire field (chap. v, p. 128) north of Melton Mowbray; another is the Oxfordshire field (chap. v, p. 136) around Banbury. In its further prolongation south-westward through Gloucestershire and beyond, the Middle Lias includes some thin seams and nodule-bands of ironstone, but not in quantity sufficient for working.

Upper Lias.

The Upper Lias in England is mostly a shaly formation with some thin earthy limestone in places. The shales are often pyritous and may contain up to 7 per cent. of iron, and frequently include bands of nodules, but no workable iron-ore has been found in them. The occurrence of the Raasay ore in this division in Scotland has already been mentioned.

Lower Oolites.

The Lower Oolites, which come next to the Middle Lias in importance as a source of iron-ore, are a variable series of deposits,

among which limestone generally predominates, except in North Yorkshire where the division is composed mainly of sandstones and shales or clays with relatively thin and impure calcareous bands. Some of the thicker and more extensive sheets of limestone are remarkably pure, but many of the thinner bands are variably intermingled with sandy and clayey material, and are generally more or less ferruginous. Occasionally, in the lower part of the division, there has been a local concentration of iron, which appears to have replaced the calcareous constituents of the rock, and in these places the rock becomes a valuable ore. The chief deposits of this kind occur in Northamptonshire and the neighbouring counties where the ferriferous rock varies from 6 feet to 15 feet in thickness, and carries on the average, about 32 per cent. of iron. Though the ores of this field have been worked for many years, only the outcrop of the band has as yet been broached and the reserves are so large that this area is likely to become of increasing importance to the iron industry (chap. vi). South-westward the rocks of this belt change their character and contain no workable ore, while to the northward of Grantham the ore-bed deteriorates and becomes patchy, so that no great yield can be expected from it. In Yorkshire although the whole sequence of the Lower Oolites is different, there is again a well-marked concentration of iron in the lower beds, known as the 'Dogger,' and, in the aggregate, a considerable quantity of ore has been obtained from the richer patches, which appear now, however, to be nearly exhausted (chap. ii, pp. 25-31). Some thin bands of ironstone also occur in the higher part of the series in Yorkshire, but are hardly likely to prove of economic value.

Middle Oolites.

The most persistent member of the Middle Oolites is a thick mass of clay, the 'Oxford Clay,' which forms the middle of the division and is nearly continuous in the interior from the coast of Yorkshire to the coast of Dorset. The clay contains a little disseminated iron but nowhere yields iron-ore. It passes downward into sandy calcareous beds, the 'Kellaways Rock,' which are often locally ferruginous, but not rich enough for present-day requirements, though they appear to have been smelted on a small scale at some time in the past in North Yorkshire ('Jurassic Rocks,' vol. i, Yorkshire' p. 434). In some of the recent borings in Kent in which the Kellaways Rock was passed through, it was more than usually ferruginous, but is said to contain too much sulphur to be acceptable as an ore (*see* pp. 225–6 for analyses).

Above the Oxford Clay there comes a variable series, named the Corallian Beds, consisting partly of limestones and partly of calcareous sandstones, clays, and ferruginous marls or marlstones. The mixed beds of this series are often sprinkled with round polished grains of ferric oxide, and in places these 'iron-shot' grains are segregated thickly enough to bring the rock into the grade of an iron-ore. This is the case at Westbury in Wiltshire and at Abbotsbury in Dorset, the ore in both districts occurring at about the top of the Corallian beds, though, on the evidence of its fossils, the Abbotsbury deposit is now believed

to range above the Corallian into the lower part of the overlying division, the 'Kimmeridge Clay.' The yield of iron from these ores ranges from 30 to 40 per cent.; they are extensively worked at Westbury (*see* chap. vii, p. 216). A similar ore-bed has been found at a slightly lower level in Corallian rocks in deep borings in East Kent, and is likely to become of economic consequence (*see* p. 223).

Upper Oolites.

Whatever iron there is in the Upper Oolites is sparsely disseminated, and nowhere in England has any ironstone of economic value been found in this division unless we reckon the Abbotsbury deposit, mentioned in the last paragraph, as belonging to it. Its lower part is made up of the Kimmeridge Clay, consisting mostly, as the name implies, of clay or shale, but occasionally with sandy calcareous bands toward the base which are sometimes 'ironshot.' The Portland Beds, next above the Kimmeridge Clay, are mainly composed of sand, calcareous sand and limestone; and the Purbeck Beds, at the top of the division are a variable and thin-bedded series of clays, shale, and impure limestones, with much gypsum in places.

Cretaceous.

The Lower Cretaceous rocks in many parts of their range are more or less ferruginous, but rarely approach the ore-quality. In the Upper Cretaceous, iron is scarce throughout excepting very locally in thin bands at the base of the Red Chalk in the north, and of the Gault in the south, which are not likely to have economic value.

At present no Cretaceous ironstone is being worked in England, though some Lower Cretaceous ores have been got in recent times and may be opened up again in the future. Chief among these are the deposits in the neighbourhood of Claxby and Tealby in Lincolnshire (described in chap. vii, p. 210), and those of Seend in Wiltshire (chap. vii, p. 220). Sandy beds that, from the iron-content alone, might be regarded as lean ore occur in other parts of the outcrop, *e.g.*, at Kirby Underdale, East Yorks. (p. 208) and Midhurst, West Sussex (p. 228), but the high percentage of sand at present renders them practically worthless. If some cheap method could be devised for concentrating the iron particles and separating them from the bulk of the sand-grains, these deposits would become serviceable. Therefore they deserve to be taken into account in considering the iron-reserves of the country. In other parts where the distributed iron-content of the sands may be so low as to be quite negligible, there has frequently been a cementation of the sand by iron-oxide along joints and bedding-planes forming thin cakes or seams of 'hard-pan' or 'ferricrete' rich enough to be reckoned as lean siliceous ore. The quantity of this material in any particular district is not enough to justify the working of the deposits for its recovery, but where they are worked for other purposes small lots might be cheaply obtainable

from time to time from the spoil. The Lower Greensands of Bedfordshire and West Sussex are areas in which such material is fairly plentiful.

Clay-ironstones, somewhat similar to those of the Coal Measures in composition and in mode of occurrence, are widely distributed in the Wealden deposits of Kent and Sussex, being most abundant in the subdivision known as the Wadhurst Clay. They occur both in the form of nodules and in thin lenticular bands. In old times they formed an important source of British ore, being smelted in the neighbourhood of their occurrence with charcoal produced from the Wealden forests. The industry lingered on into the beginning of last century and was then extinguished. Both the quantity and the quality of the ironstone are such that there is little prospect of its revival even under the change of conditions brought about by the discovery of deep-seated coal in Kent. Some further account of the ore and of the old industry is given in chap. vii, p. 226.

Tertiary.

Sparingly-ferruginous deposits occur at several levels in the Tertiary strata of the South and South-east of England, but nowhere in quantity or quality sufficient to make them of worth. At one English locality, however, viz., Hengistbury Head near Bournemouth, a concretionary iron-ore of Tertiary age was quarried and also collected from the shore in some quantity for shipment to distant smelting centres about the middle of last century (p. 229). The ore is reported to contain about 30 per cent. of iron. Other occurrences of Tertiary ores are mentioned on p. 230.

CHAPTER II.

CLEVELAND DISTRICT (LIAS AND OOLITE).

By G. W. Lamplugh.

INTRODUCTION.

Among the stratified iron-ores of Britain those of the Cleveland district, North Yorkshire, take first rank, both in respect to output and industrial consequence. These ores occur as interbedded deposits in the upper part of the Middle Lias, and are almost wholly obtained from a band known as the Main Seam. After some minor trials on the coast, the exploitation of the Main Seam on a large scale was begun in the year 1850 at its northern outcrop near Eston. It rose rapidly to a great industry and has since been continuous, the annual output of ore for the last 50 years averaging close upon six million tons (*see* p. 35). The growth of the town of Middlesbrough and of the iron and shipping industries of the Tees estuary have been due mainly to the development of the Cleveland ironstone.

The geological, chemical, industrial and historical aspects of the Cleveland field have given rise to an extensive literature, to which references will be found in the selected list given on p. 63. The country was mapped by the Geological Survey, on the scale of 6 inches to the mile, about 40 years ago; geological maps on the scale of 1 inch to the mile were published for the whole area, and on the 6 inch scale for the neighbourhood of the coast and part of the ironstone field. The maps were accompanied by descriptive Memoirs and by separate Sheets of Horizontal Sections (for titles and particulars *see* Bibliographical List). The purpose of the present account being to deal with the conditions now existing, the reader is referred to the previous literature for the history of the industry and for discussions as to the origin of the ore, etc. The following stratigraphical particulars are largely compiled from the Geological Survey Memoirs above referred to.

Stratigraphy of the Ore-beds.

In North-east Yorkshire the upper part of the Middle Lias is characterised generally by the presence of ferruginous bands traceable over wide areas, but showing lateral changes in thickness and composition.

The following is a generalised section through the series in the northern part of the district, where the ironstone is most plentiful:—

			Thickness. Feet.
	Upper Lias Shales	... ...	—
Middle Lias.	Ironstone Series	Shale, or dogger, variable	0 to 6
		Main Seam of ironstone	6 ,, 11
		Shale and 'Black Hard'	2½ ,, 5
		Pecten Seam (alternations of ironstone and shale, variable).	1½ ,, 6
		Shale	3 ,, 6
		Two-foot Seam	1½ ,, 2½
		Shale	20 ,, 30
		Avicula Seam (ironstone and shale, discontinuous).	0 — 3
	Sandy Series ...	Sandy shales and flaggy calcareous sandstones	70 to 90
	Lower Lias shales and sandy calcareous bands.		

The stratigraphy of the district is shown on the Geological Survey 1 inch = 1 mile Map, Sheet 34 New Series, which covers nearly the whole of the active mining area. The structure is fully illustrated by the Sheets of Horizontal Sections, Nos. 131, 132, 133 and 134, with short accompanying 'Explanations,' published by the Survey. (*See* also Bibliographical List, p. 62).

The general dip of the strata is south-eastward, so that the ironstone series is highest above sea-level in the north-westward part of the district; but faults and undulations interfere locally with this prevalent arrangement. Most of the faults are too small materially to affect the mining of the ironstone, but two are of consequence in this respect: (1) The Upsall Fault, running E.N.E.-W.S.W. south of the Eston Hills, with a northerly downthrow having a maximum of about 400 feet but diminishing rapidly eastward, cuts out the ironstone in a broad wedge-shaped tract expanding westward from Guisbrough, and causes a duplication of the outcrop; (2) The Lockwood Beck Fault, running nearly N.-S., has an easterly downthrow which attains 240 feet in the Stanghow Mine but diminishes northward; it forms a barrier between the workings which reach it from the opposite sides. The undulations, causing broad synclines and anticlines in several parts of the mining district, are described in detail in the 'North Cleveland' memoir (pp. 74-76); their principal economic effect is to carry down the ironstone in the south-central part of the mined area, so that at the bottom of the basin (in the Liverton and Kilton Mines) it lies more than 250 feet below sea-level. The mines around the edge of the basin are mostly worked by day-levels; those within the depressed area are shaft-mines, the sinking being carried down through the overlying Oolites and Upper Lias to the Ironstones. The deepest shafts at present working are (depths to Main Seam):—North Skelton 720 feet, Kilton 680 feet, and Lingdale 620 feet.

At present no ironstone is won from the Middle Lias south of the Leven-Esk valley, though the Main Seam was formerly mined rather extensively at Swainby on the western escarpment (Fig. 4, p. 18), and the Pecten and Avicula seams at Grosmont and the neighbourhood (pp. 20, 24). The formation continues to include ferruginous bands as far south as the Derwent, but not of workable quality or thickness. Between the Derwent and the Humber

the Middle Lias is always thin, and in places absent. Ferruginous bands have been observed in it near Goodmanham (Market Weighton district) and below Sancton; an analysis of the rock at Cauldwell Spring near the last-mentioned place yielded, in the dried stone, iron, 22·80; silica, 8·80; lime, 20·50 per cent., etc., with iron in the calcined stone, 31·45 per cent.[1]

Composition of the Ore.

The following description of the ore from the Main Seam near the northern outcrop is given by Mr. A. Dick.[2] All the Middle Lias seams of the district are essentially similar in composition, but they show much local variation in the proportion of the oolitic granules to the matrix, and in the amount of sandy, clayey and limy matter present.

"*Description.*—Chiefly a carbonate of protoxide of iron: lustre, earthy; colour, greenish grey; streak, similar; fracture, uneven, showing here and there small cavities, some of which are filled with carbonate of lime. Throughout the ore are diffused irregularly a multitude of small oolitic concretions, together with small pieces of an earthy substance resembling the ore but lighter in colour. When a mass of this ore is digested in hydrochloric acid till all carbonates and soluble silicates are dissolved, there remains a residue having the form of the original mass of ore. It is extremely light, and falls to powder unless very carefully handled. It contains the oolitic concretions, or else skeletons of them, which dissolve completely in dilute caustic potash, showing them to be silica in a soluble form. Under the microscope some of them are seen to have a central nucleus of dark colour and irregular shape, but none of them present any indication of organic structure or radiated crystallization. If the residue, after having been digested in caustic soda, be washed by decantation, there remains a small number of microscopic crystals; some of these, which are white, are quartz, and others, which are black and acutely pyramidal, consist chiefly of titanic acid."

Mr. Dick also notes that some of the angles of the dark crystals were found to correspond to similar angles in anatase, and that the green colour of the ore seems to be due to a silicate containing peroxide and protoxide of iron. He likewise gives a full analysis of the ore.

More recently, Dr. J. E. Stead, F.R.S., has published an exhaustive study of the microscopical, mineralogical, and chemical characters of the ore of the Main Seam[3], from which, with his permission, the following analyses and other particulars are reproduced.

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[1] 'The Geology of the Country between York and Hull' (*Mem. Geol. Surv.*), 1886, p. 16. (Full analysis given.)

[2] From 'Iron Ores of Great Britain.' Part i. (*Mem. Geol. Surv.*), 1856, p. 97.

[3] 'Cleveland Ironstone and Iron,' *Proc. Cleveland Inst. of Eng.*, 1910: and separate (Middlesbrough, 1910), pp. 1-45, with 16 plates, many analyses etc.

GENERAL AVERAGE OF CLEVELAND IRONSTONE.
(*Dr. J. E. Stead.*)

	Weight. Per cent.	Vols. in c.c. in 100 grms. of stone. Per cent.	Volume parts per 100 Per cent.
Ferrous oxide	32·50	—	—
Ferric oxide	3·00	—	—
Manganous oxide	0·7	0·14	0·40
Alumina	10·2	2·50	7·00
Lime	5·0	1·51	4·30
Magnesia	3·5	0·97	2·80
Carbon-dioxide	19·0	—	—
Silica	13·5	5·10	14·66
Titanic acid	0·3	0·07	0·22
Sulphur	0·2	0·10	0·28
Phosphoric acid	1·0	—	—
Phosphorus	0·43	0·22	0·66
Carbonaceous matter	0·20	0·20	0·56
Combined water	2·30	10·90	30·43
Moisture	8·00		
	100·80		
Iron	27·38	3·48	9·97
Loss by calcination	26·29	—	—
Iron in calc. stone	37·20	—	—
Yield of Pig Iron	29·61	—	—
Specific gravity, raw stone ...	2·86		
Specific gravity, calcined stone	2·11		

Addendum by J. E. S.—The potash varies between 0·1 per cent and 0·6 per cent.

CONSTITUTIONAL ANALYSIS.
(*Dr. J. E. Stead.*)

		Weight. Per cent.	Volume. Per cent.
Siderite	FeO 27·91 CO_2 17·06	44·97	32·92
Limonite	Fe_2O_3 3·0 H_2O 0·51	3·51	2·50
Iron pyrites	Fe 0·17 S 0·20	0·37	0·22
Manganese carbonate ...	MnO 0·70 CO_2 0·44	1·14	1·06
Calcite	CaO 1·91 CO_2 1·50	3·41	3·52
Phosphate of Lime ...	Ca_3O_2 1·18 P_2O_5 1·00	2·18	1·91
Ammonia, Potash, etc. ...	... ...	0·29	0·22
Clay	FeO 4·37 SiO_2 13·50 Al_2O_3 10·21 CaO 1·32 MgO 3·50 H_2O 2·98	35·88	34·57
Carbonaceous Matter	... ...	0·20	0·56
Moisture	... ...	8·00	22·43
		99·85	100·00
Specific gravity, calculated		2·84	
Specific gravity, actual		2·86	
Metallic Iron		27·38	9·97
Pig Iron		29·61	

With regard to the above, Dr. Stead notes—

"This, I believe, is the first time any attempt has been made to calculate the constitution of average Cleveland Ironstone . . . On comparing the analyses of the ironstone in Appendix IIA and IIB [a series of 23 analyses supplied to Dr. Stead by ironmasters and mine owners] it is evident that there is not any great variation in the lime, magnesia, and phosphoric acid. The principal variables are the iron-bearing minerals and silica. As the iron decreases the silica increases. It has long been recognised that, given the amount of iron in calcined Cleveland stone, the general character and approximate composition may be inferred . . .

"The porosity of the stone is indicated by the quantity of free water the stone can contain. This in the case of the raw stone with 8 per cent. water is about 22 per cent. of its actual volume . . . When the stone is properly calcined it loses about 27 per cent. of its weight, but retains its original volume . . .

"This will partly explain why it is that Cleveland stone is so readily reduced in the blast furnace. The stone resembles a sponge, through which at the top of the furnace the reducing gases readily penetrate, with the result that reduction is rapidly effected."

In describing the accessory minerals of the ore Dr. Stead has the following remarks:—

"MIXED SILICATES.—It is a difficult matter to say what is the chemical constitution [of the argillaceous matter forming] about one-third of the mass of Cleveland ironstone. There are probably many minerals including silicate of iron. . . . Minerals containing vanadium and chromium are also present as these metals are found in minute quantities in Cleveland pig iron, but they have not been identified in the stone." . . . "ZINC BLENDE . . . is always present in the fine dust from blast furnaces which smelt the stone. It is often present as sulphide or zinc blende in the Cleveland dogger stone." . . . "IRON PYRITES. Bisulphide of iron is always present in the oolitic grains of the sulphur bed [*see* p. 14]. It is found in some pieces of petrified wood, having replaced the woody fibre. It is also diffused in minute specks throughout the bed of ironstone." . . . "BARIUM SULPHATE is a very common constituent of some pieces of fossilised wood . . . associated with calc-spar, pyrites, and sometimes with irregular shaped pieces of jet or coal." The analysis of a mixture of a large number of specimens of fossil wood from the Main Seam by Dr. Stead also revealed the presence in small but determinable quantities of sulphide of arsenic (0·830 per cent.); sulphide of copper (0·074 per cent.); sulphide of lead (0·184 per cent.); sulphide of nickel (1·540 per cent.); sulphide of cobalt (0·460 per cent.); and peroxide of manganese (0·180 per cent.). "MANGANESE CARBONATE. The quantity of manganese is small [in the ore] and one cannot be certain in what state of combination it exists. As, however, it is common to find it in spathic ores the probability is that it exists as carbonate in the Cleveland stone." . . . "CALCIUM PHOSPHATE. The whole of the phosphoric acid exists in combination with lime, but I have not yet detected any fibro-crystalline crystals of apatite." . . . "PETROLEUM is found in minute quantity, indeed, most of the ironstone at a depth has a distinct smell of petroleum oil." . . . "TITANIC ACID exists in small fibro-crystalline crystals in the form of octahedrite and Mr. C. R. Linsley, B.Sc. has discovered crystals of brookite in Upleatham ironstone, associated with Anatase, Rutile and Tourmaline" (*Mineralog. Mag.*, 1905, vol. xiv, pp. 96-98).

As regards the origin of the ore, Sorby's explanation is generally accepted[1], that the rock was deposited as an oolitic limestone, and that the greater part of the lime was afterwards replaced by iron through the agency of percolating solutions. In other British and foreign ores of somewhat similar character, however, there are indications that the ferruginous oolitic granules may

[1] H. C. Sorby, *Proc. Geol. and Polytech. Soc. W. R. Yorks.*, vol. iii, 1876, p. 457; and 'Anniversary Address,' *Quart. Journ. Geol. Soc.*, vol. xxxv, *Proc.*, p. 84.

have been formed as such during the deposition of the strata[1], so that the replacement theory may eventually be found to require modification.

Description of the Seams.

The ironstone bands, like all sedimentary deposits, show changes of character when traced from place to place, consequent upon the variable local conditions on the sea-floor of the period, due to differences of depth, currents, supply of sediment, etc. The ruling effect of these differences is that the bands show comparatively little variation if followed in the direction of prevalent strike, viz., E.N.E.—W.S.W., but deteriorate rapidly both in thickness and quality in the direction of dip, or towards S.S.E. This deterioration is best recognised in the Main Seam because this seam has been so widely worked, but, with some local exceptions presently to be noted, it affects all the seams, and is evidently dependent upon some original condition, such as the position of the coast-line when the beds were deposited, or the force and direction of the sea-currents of the period.

In the following short description of the individual seams, the general bearing of these changes upon the ironstone resources of the district is indicated.

Main Seam.

The Main Seam attained its maximum thickness and value as an ore at its north-westerly outcrop on the northern side of the Eston Hills, where it is now practically worked out. The following was the section near Court Green ('North Cleveland' memoir, p. 21).

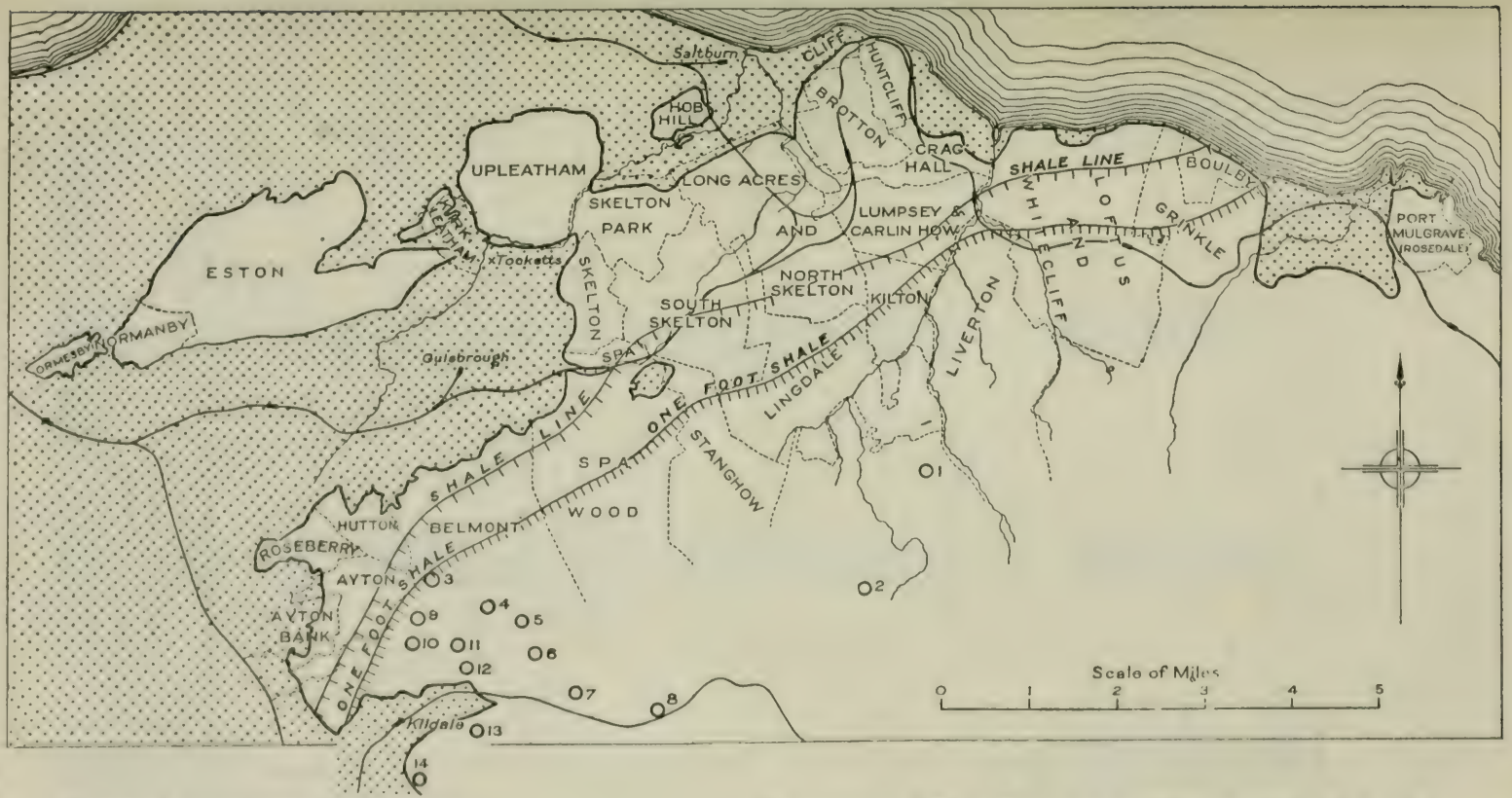
	Ft.	In.		Ft.	In.
Hard ironstone, impure; used for a roof in mining				3	0
Band of iron pyrites in oolitic grains ['Sulphur Band'] ...				0	6
Main bed of blue oolitic ironstone. Main Seam				11	0
Mottled shale and ironstone, in streaks	1	1			
Dogger (ironstone) band	0	4			
Masses of shells, *Pecten*, *Avicula*, etc.	0	5	Pecten Seam	2	10
Mottled shale and ironstone, shelly base	0	5			
Shale and ironstone, shelly	0	7			

In this section the Pecten Seam, which farther westward thickened to nearly 5 feet, comes immediately beneath the Main Seam, and could be worked along with it. But to the south and east a band of ferruginous shale sets in between the two, and the Pecten Seam itself degenerates into thin alternations of shale and ironstone of little or no value as an ore.

Eastward for 8 or 9 miles, to its termination near the coast between Saltburn and Skinningrove, the Main Seam continues as a single bed, with the Sulphur Band and impure stone or 'dogger' above it, and a hard ferruginous mudstone, known as the 'Black

[1] *See* discussion on the origin of the Clinton ores of the Birmingham District, Alabama, by E. C. Eckel, in *Bulletin* 400, *U.S. Geol. Survey*, 1910, pp. 28-38. The Clinton ores resemble in many respects the Cleveland deposits, though of different geological age.

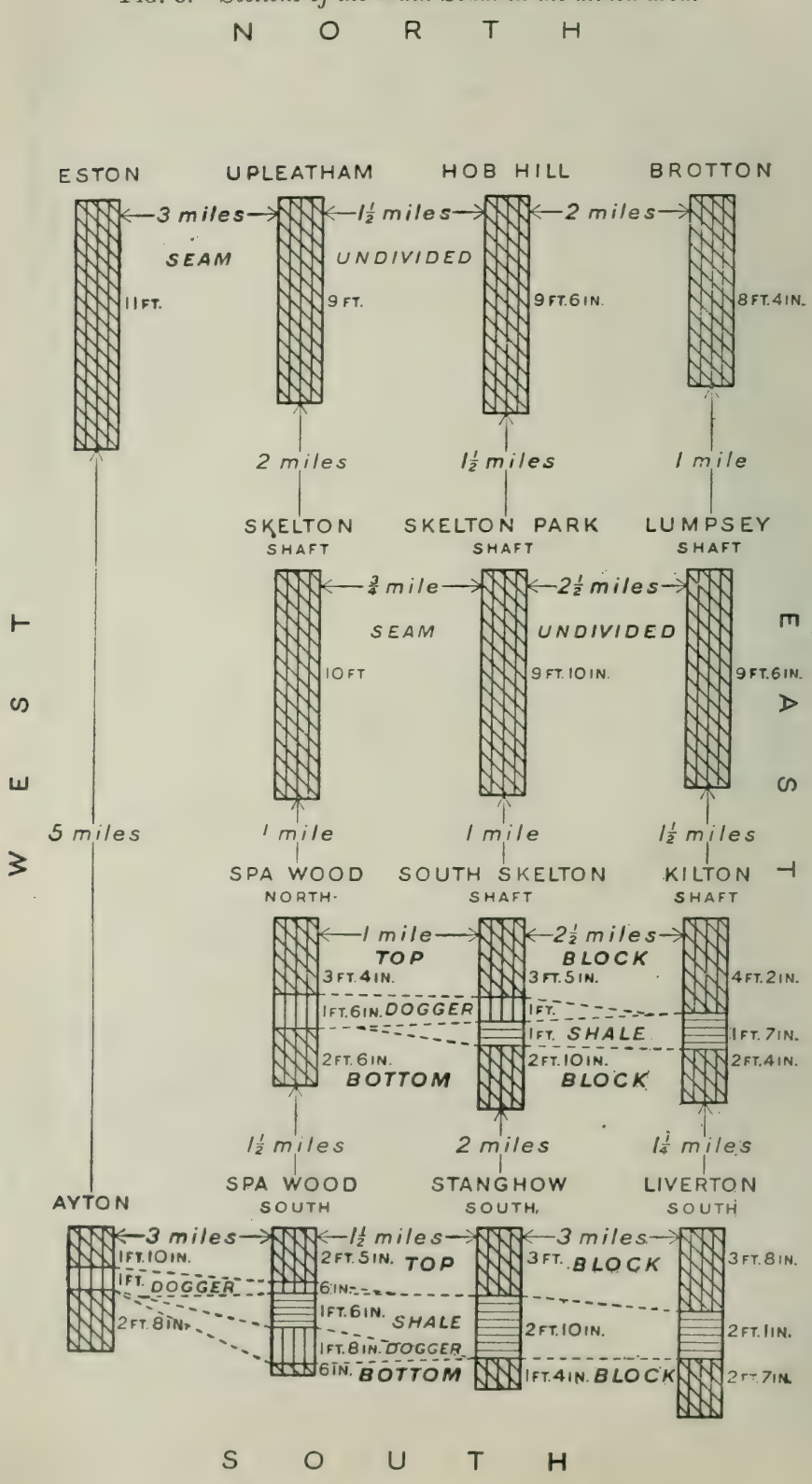
FIG. 2.—*Sketch-map of the mining area in the Cleveland Main Seam.*



Names of mining properties, in capitals.
Outcrop of Ironstone, shown by thick line.
Beds below Ironstone, stippled.

Shale-parting of Main Seam sets in at 'SHALE LINE' and is 1 foot thick at line marked 'ONE FOOT SHALE,' increasing southward.
Sites of borings shown by circles with numerals.

FIG. 3.—*Sections of the Main Seam in the mined area.*



Hard,' at its base; but the thickness of the ore-bed diminishes to about 9½ feet at Upleatham and about 8½ feet near the coast (*see* sections Fig. 3). Southward, however, it loses its homogeneity, and within two or three miles, becomes split into two portions, at first by a band of hard 'doggery' ironstone which still constitutes an ore, and afterwards by a parting of ferruginous shale which is actually detrimental if smelted with the ore. The line along which the shale-parting sets in is shown approximately in the sketch-map, Fig. 2. The present reserves of ore lie principally to the south of this line.

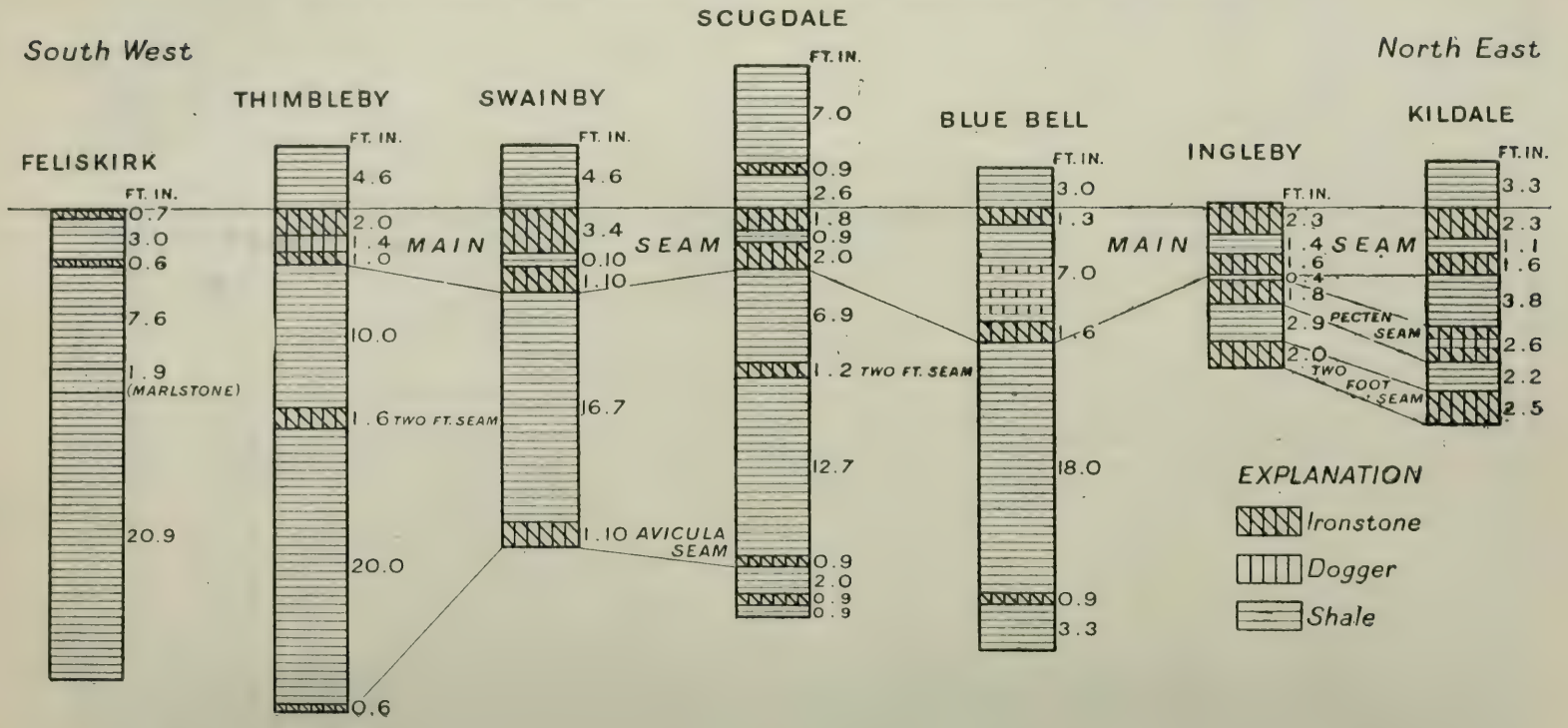
The shale parting expands steadily southward at the expense of the ore, now divided into a 'Top Block' and a 'Bottom Block,' and the ore deteriorates in quality as well as in thickness.

There are local irregularities in the thickening of the shale-band, but its expansion in the direction of dip may be stated roughly as being about 1 foot per mile; the position at which it attains a thickness of 1 foot is shown on the sketch-map by a second line. In the most southerly workings of the mined area (Fig. 3) it has expanded to 2 feet or over, with 3 to 4 feet of ore-stone above it in the 'Top Block,' and 1½ to 2½ feet of ore-stone below it in the 'Bottom Block.' From the evidence of borings and from the study of the natural exposures it is clear that the impoverishment southward and eastward continues progressively, so that in the Esk valley and on the coast south-east of Whitby the seam has faded out of recognition, or is doubtfully represented by bands of nodules only. This progressive deterioration is brought out in the serial sections Figs. 4 and 5.

The area and other conditions of the Main Seam where it is recognised to exist as a productive iron-ore being thus known, its reserves may be (and have been) calculated with approximate definiteness. But there remains the uncertain factor as to the point at which the southward workings must be permanently stopped by the cost of the material exceeding its market value. Under pre-War conditions it was believed that in the southerly belt of mines the opening up of the seam had been pushed as far as would be profitable. Whether new conditions will render the impoverished ore profitable in a farther belt depends, of course, entirely upon the future course of the iron industry as a whole, at present incalculable. As matters stand, the thickest and best area of the Main Seam, *i.e.*, the area north of the Guisbrough valley and of a line drawn from Guisbrough to the coast at Skinningrove, is approaching exhaustion; the middle belt of medium ore, averaging about 2 miles in breadth is opened up by mines along the whole of its course, but still contains reserves sufficient for another 25 to 30 years at the pre-War rate of output; and if the workings can be profitably extended to the southward along the whole belt, a further reserve of about 150 million tons may be counted upon in a breadth not exceeding another mile and a-half, beyond which there is little or no prospect that the Main Seam can ever be worked.

The condition of the beds at and about the horizon of the Main Seam in the country south of the recognised mining area is illustrated by the serial sections in Figs. 4, 5 and 6. Attempts to

FIG. 4.—*Sections of the Ironstone Series along the Western Escarpment in Cleveland.*



work the impoverished seam have been made at several places in this ground on and near the western escarpment (*see* Lists, pp. 36, 37) but always without success. In the escarpment south of the Leven valley, the seam is recognisable at least as far as Thimbleby (Fig. 4), and in part of this tract it is not much worse than in the doubtful belt south of the present mines, so that some working might be possible here if conditions in the future should become such as to encourage the extension of the Cleveland mines into the poorer ground. The series of analyses from the section at Ingleby Greenhow, reproduced on p. 52, shows the composition of the beds in this tract where the degeneration of the seam is becoming marked.

Eastward from the escarpment, where inliers of the Ironstone Series are exposed in the deep valleys of Bilsdale, Bransdale, Farndale, Rosedale, Basedale, Westerdale, Danbydale, Great and Little Fryup, Glaisdale and Eskdale (*see* sections, Fig. 6), the Main Seam continues to degenerate until it is represented only by thin interrupted layers of stone and bands of nodules in shale, and it is in this condition that the belt emerges again in the coast-section at Hawsker between Whitby and Robin Hood's Bay (*see* Fig. 5). In this belt it is often more or less doubtful what particular beds should be taken as equivalent to the Main Seam, but in any case it is clear that the belt possesses little or no prospective value as a source of ore.

Pecten Seam[1].

At the north-western outcrop in the Eston Hills, the Pecten Seam, as already mentioned, comes immediately beneath the Main Seam, and was in some places worked along with it. It has also been got to some extent along its outcrop at Upleatham, where it is separated from the Main Seam by 5 feet of shale. But, in North Cleveland, it is only in this western part of its outcrop that the seam has been worth working as an ore. Like the Main Seam and the Two-foot, it deteriorates to the east and south, and passes into stringy alternations of thin or nodular ore-bands and shale, with here and there a little good stone, but averaging so low as to be of no present, and slight prospective, value. In the Esk valley, however, a seam believed to be its equivalent is of rather better quality and has been mined in the neighbourhood of Grosmont. In North Cleveland its limits are frequently ill-defined, owing to its thin-bedded shaly character, and, in the sections given below, the limits assigned to the seam are probably not always the same. Indeed, in certain cases the seam has escaped recognition altogether, and its name has then been misapplied to the next lower seam, the Two-foot, which is of different character. This misapprehension explains some confusion that has arisen in local opinion concerning the respective seams.

Mr. G. Barrow[2] estimated in 1879 that, allowing the seam to cover an area of about 50 square miles, and to contain an average thickness of $2\frac{1}{2}$ feet of iron-ore, it might hold, roughly, 400 million tons of ore, but he was doubtful how much of this would

[1] For much information respecting the minor seams, as well as with regard to the Cleveland ironstone industry generally, I have particularly to thank Mr. J. J. Burton, F.G.S., Mr. W. Charlton, and the late Mr. C. Heslop.

[2] *Proc. Cleveland Inst. of Eng.* for 1879-80, p. 182.

be workable. Later developments tend to show that over most of the estimated area the seam has less value than was thought, and is not likely ever to be worked. Even where its condition is best, there is not much prospect that it can be mined independently on a large scale, unless the smelting practice and general condition of the Cleveland iron industry become greatly modified. In a few places at and near the north-western outcrop, the better bands contained in the seam may be broached to some extent in existing workings when the Main Seam is exhausted; and in the Grosmont area there may be some further stone available. But the reserves to be counted upon from this seam must be of indifferent quality and doubtful value, and in any case cannot be put at more than 40 to 50 million tons.

The variable and complex character of the seam is shown by the sections which follow (*see* also Figs. 4, 5, and 6), and by the serial analyses in the Table on p. 55, and in Figs. 8 and 9.

In the workings at Grosmont referred to above, where both the Pecten and the Avicula seams have been mined, the ore was for many years smelted at furnaces on the spot. Since their extinction, no further working has been done on the Pecten Seam, though the winning of the Avicula Seam for smelting in other Cleveland furnaces was continued at intervals up to 1915. The Avicula Seam has been mined on both sides of the Esk river in separate workings known respectively as the 'West Side Mine' and the 'East Side' or 'Eskdale Mine' (*see* pp. 24-5), but the Pecten Seam was won in the East mine only, where the area worked in this seam covers about 75 acres, with a larger area of the Avicula Seam. The workings southward on the dip in both seams appear to have been stopped by water. In the West Side Mine the Pecten Seam was not considered to be workable.

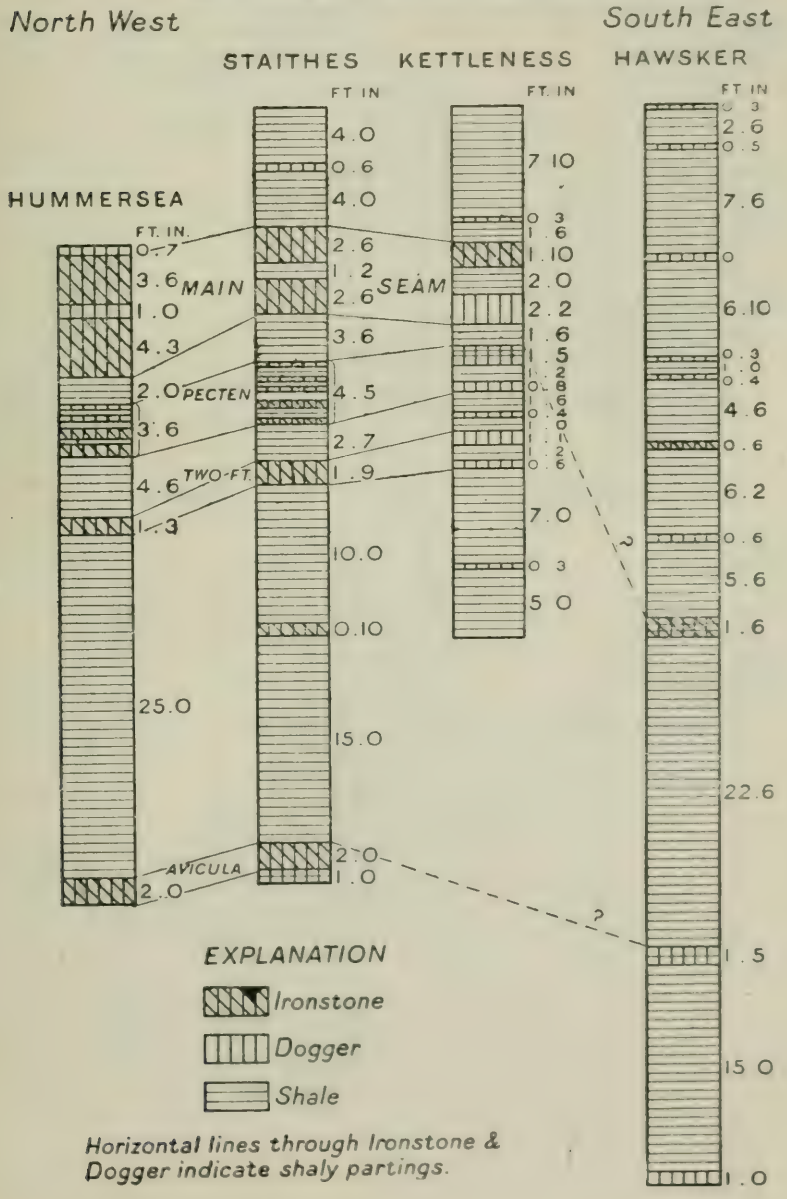
From the analyses given on pp. 56-60 it will be seen that the Pecten and Avicula seams contain more lime than is found in the Main Seam. This is advantageous in smelting and partly compensates for the lower iron-content. The sulphur, which is detrimental, tends to run rather higher than in the Main Seam. The other constituents have about the same proportions as in the deteriorated southern part of the Main Seam.

Two-Foot Seam.

The Two-foot Seam was so named from its average thickness at the northern outcrop. At some of the mines it is known as the 'Bottom Seam,' and is occasionally confused with the Pecten Seam, as already mentioned. Where best developed, it resembles the Main Seam in structure and quality, though usually a somewhat harder stone. It resembles the Main Seam also in deteriorating southward and eastward, and in splitting into two blocks with a shaly parting. It lies at an average depth of 10 feet below the Main, the interval between the two being slightly less than this in the north-western part of the field, and slightly more in the south-eastern part. It has nowhere yet been worked independently but has been raised to a small extent in a few places along with the Main Seam at the northern outcrop, and may perhaps bear further development in this quarter. Its thinness must, however, retard its exploitation in the future as in the past. South of the 'Shale line' shown in the map, Fig. 2, the

seam is probably too much deteriorated to be serviceable as an ore under the normal conditions of the iron industry. In considering the Cleveland ore-reserves therefore, the contents of the seam south of this line have not been taken into the calculation. North of the 'Shale Line' it is calculated to contain about 50 million tons of ore averaging slightly under 30 per cent. iron. The thickness of the seam at various points is shown in the series of sections given on p. 22 and in Figs. 4, 5 and 6. Its composition is illustrated by the analyses on p. 59 and Figs. 8 and 9.

FIG. 5.—*Coast-sections of the Ironstone Series of Cleveland.*



Sections in the Pecten and Two-foot Seams.

(*See also* pp. 55, 59 and Figs. 4, 5 and 6.)

Roseberry.

	Ft.	in.
Main Seam		
Hard Shale	3	0
Pecten Seam—		
Alternations of thin ironstone and shale.	3	6
Shale	3	0
Two-Foot Seam—		
Ironstone, in three blocks, with thin shaly partings.	2	2
Shale	6	0
Oolitic ironstone	1	1

Upleatham.

	Ft.	in.
Main Seam		
'Black Hard' and Shale ...	5	0
Pecten Seam—		
Shelly ironstone with partings: average—	2	10
Shale	5	0
Two-Foot Seam—		
Ironstone	2	2

(*See* 'North Cleveland Memoir,' p. 21.)

(For analyses of Pecten Seam *see* p. 54.)

Carlin How.

	Ft.	in.
Main Seam		
'Black Hard'	3	3
Pecten Seam—		
'Pecten band'	3	4
Shale	6	0
Two-Foot Seam—		
Ironstone	1	10

(For serial analyses *see* p. 59.)

Spa Wood, East.

	Ft.	in.
Main Seam		
'Black Hard'	3	0
Pecten Seam—		
Ironstone and shale ...	6	8
Shale	4	0
Two-Foot Seam—		
Ironstone (top block) ...	0	10
Shale	0	3
Ironstone (bottom block) ...	1	9

(For diagram of analyses, *see* Fig. 9, p. 57.)

Brotton.

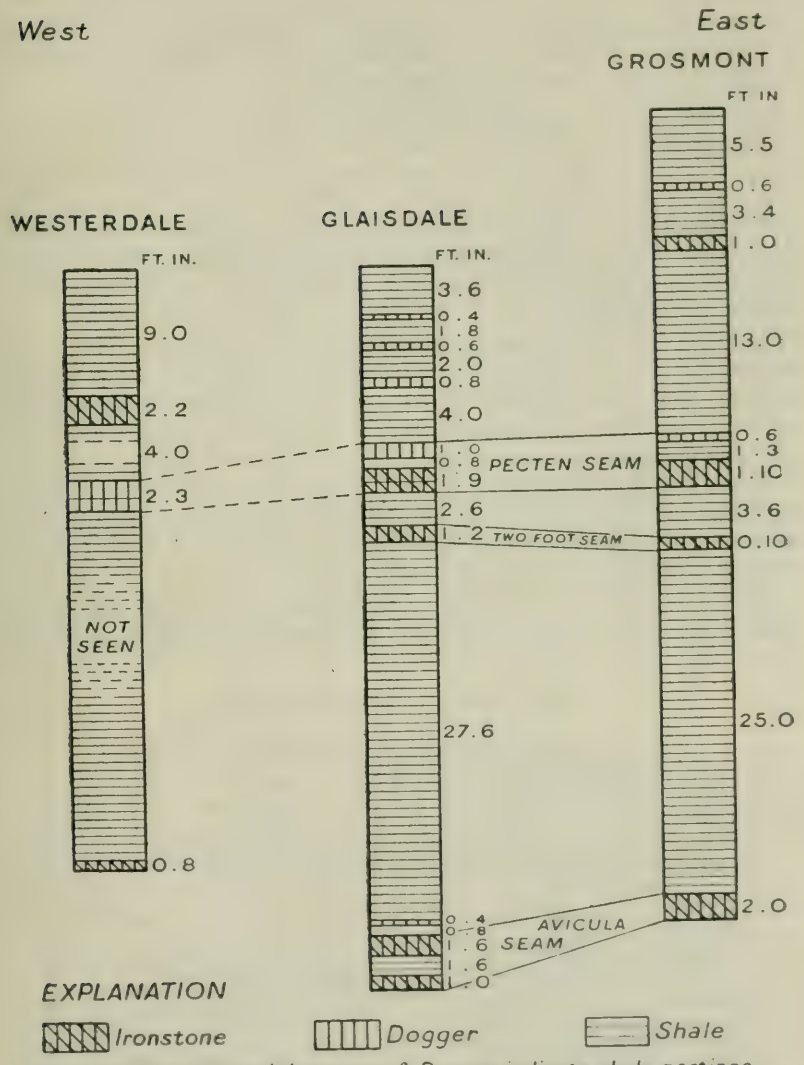
	Ft.	in.		
Main Seam				
'Black Hard'			2	2
Pecten Seam—				
Ironstone	0	$4\frac{1}{2}$		
Shale	0	$1\frac{1}{2}$		
Ironstone	0	$6\frac{1}{2}$	2	$4\frac{1}{2}$
Shale	0	$8\frac{1}{2}$		
Ironstone	0	$7\frac{1}{2}$		
Shale			5	$6\frac{1}{2}$
Two-Foot Seam—				
Ironstone			2	4

(For analyses of Two-foot Seam *see* p. 59.)

Liverton.

	Ft.	in.		
Main Seam				
'Black Hard'			0	7
Shale			3	$7\frac{1}{2}$
Pecten Seam—				
Ironstone ...	0	5		
Shale ...	0	$4\frac{1}{2}$		
Ironstone ...	0	$5\frac{1}{2}$		
Shale ...	0	8	3	$9\frac{1}{2}$
Ironstone ...	0	11		
Shale ...	0	4		
Ironstone ...	0	$7\frac{1}{2}$		
Shale			6	4
Two-Foot Seam—				
Ironstone (poor)			1	6
Shale			20	0
Avicula Seam—				
Ironstone ...	1	0		
Bastard Dogger	0	2		
Brown Dogger	0	4		
Dark Dogger	0	4	6	9
Shale ...	1	6		
Bastard Stone	2	0		
Ironstone ...	0	8		
Bastard Stone Shale, etc.	0	9		

FIG. 6.—*Sections of the Ironstone Series in the Cleveland dales.*



Avicula Seam.

The ferruginous band known as the 'Avicula' (from its characteristic fossil) or 'Low' Seam, has been recognised in many parts of the Cleveland district, but is usually too thin and variable to be of worth. In the lower part of the Esk valley, however, it becomes of some consequence and has been mined rather extensively in the neighbourhood of Grosmont, where its exploitation had, in fact, begun before the workings of the Main Seam in North Cleveland were established.

At the northern outcrop the band has been identified in the cliff-sections at Hummersea and Staithes, where it has a thickness of 2 feet and occurs at 30-40 feet below the Main Seam (*see* Fig. 5). Inland, it is present in the Skelton Beck section, west of the viaduct, at about 34 feet below the Main Seam, again with a thickness of 2 feet; and in the Guisbrough district, a little south of Waterfall, it is 1 foot 10 inches thick, at 41 feet below the Main Seam.[1]

It appears to have been proved at Skelton Park Mine, at 30 feet below the Main Seam, its thickness here being 1 foot 8 inches; and at the Liverton Mines, at about 35 feet below the Main, where it consists of alternations of ironstone, 'dogger,' and shale having a total thickness of 6 ft. 9 in. (*see* previous section, p. 22). It is probably represented also in the western escarpment (Fig. 4), south-west of the mining district, where, however, as previously mentioned, the correlation of the seams is more or less doubtful, owing to variation in the principal beds.

At Grosmont (Fig. 6) in the neighbourhood of the mines, the following section was measured in the banks of the Esk ('Eskdale, Rosedale,' etc. memoir, p. 8).

Section of the Ironstones near Grosmont.

	Ft.	In.
Indurated shale band, few ironstone nodules above ...	0	5
Shale with a few nodules and doggers...	5	0
Lenticular sandy ironstone band	0	6
Shale	3	4
Ironstone[2] with the large *Pecten æquivalvis*, *Belemnites*, etc....	1	0
Shale with large round doggers full of fossils	13	0
Ironstone 0 6 Shale 1 3 } PECTEN SEAM ... ... Ironstone 1 10	3	7
Shale, hard, dark, and sandy	3	6
TWO-FOOT SEAM.—Ironstone, hard, calcareous, and oolitic...	0	10
Shale	25	0
AVICULA SEAM.—Ironstone	2	0
Shale, rather sandy	6	0
Band of hard sandy shale	0	6
Hard shale, rather sandy	25	0

In the 'West Side Mines' north of the Esk at Grosmont, which have not been in operation for many years, the Avicula band was worked out over an area of about 90 acres, and the stone is reported

[1] *See Mem. Geol. Surv.* 'North Cleveland' pp. 20, 22.

[2] This is probably the representative of the Cleveland Main Seam.

to have deteriorated northward. The 'East Mines,' re-worked, after a period of inactivity, until 1915, have covered an area, in all, of about 170 acres, the composition of the Avicula Seam being as follows:—

		Ft.	in.
Shale roof		—	
Avicula Seam 3 ft. 3¼ in. ...	'Top stone' (ironstone)	0	10
	Shale	0	2½
	'Bearing stone' (best ironstone) ...	0	3
	'Thick lift' (ironstone)	1	2½
	'Thin lift' (ironstone)	0	5½
	'Bottom stone' (inferior ironstone) ...	0	3¾
	(but varying up to 8 in.)		
Shale pavement		—	

The yield of ore from the seam in these mines ranged between 7,500 and 8,000 tons per acre. Analyses will be found on p. 60. On the Murk Esk, ¾ mile south-west of Grosmont, the shaft of the old 'Esk Valley Mine,' proved the Pecten Seam, 3 feet thick, at a depth of 64 yards and the Avicula Seam, about 2 feet thick, at 70 yards ('Eskdale, Rosedale.' etc. memoir, p. 9), stone was won mainly from the latter seam, but the working was of short duration.

There is nothing to encourage expectation that this seam will ever be extracted on a large scale in the northern district, but the Grosmont area has not been worked out, and probably contains 5 to 6 million tons of stone not much inferior to that already won. A further quantity could no doubt be obtained from other parts of the field if the extraction of bands under 2 feet in thickness should ever become practicable. The total reserves of the seam are taken to be about 10 million tons.

The Dogger (Lower Oolite) Ironstone.

Besides the ironstones from the Middle Lias there has been a considerable output of ore in the Cleveland district from an irregular band occurring at the base of the Lower Oolite series, just above the Upper Lias. This band is extremely variable in composition in North Yorkshire, being sometimes a thin streak of nodules or pebbles, sometimes a thick sandstone or sandy shale, sometimes an impure limestone, but generally containing some proportion of ferruginous matter and occasionally becoming rich enough to be used as an iron-ore. The local characteristics of the band are fully described in the various Geological Survey memoirs already referred to, so that it is unnecessary to enter into particulars in the present account except regarding the places where the rock is known to be serviceable as an ore. Where worked, it is known as the 'Top Seam,' 'Dogger Seam,' or 'Oolite Seam.' The rusty look of the rock at outcrop, even where the iron-content is low, has constantly incited exploration; and along its ramifying outcrop in the moorland dales there are indications that the bed has been tested or slightly worked in many places. Some of the excavations are known to be very old but

many have been made during the last 50 or 60 years. A list of some of these trials is given on pp. 37, 38.

The only areas in which the Dogger has yielded ironstone sufficient in quantity and quality to be of commercial importance are (1) the neighbourhood of the coast, east and west of Staithes; and (2) the deep moorland valley of Rosedale, near Pickering.

(1) East of Staithes the Dogger ironstone was worked by adits in the cliff north of Hinderwell. These workings formed part of the old 'Rosedale'[1], or Port Mulgrave Mine, which also included some workings in the Main Seam of the Middle Lias, within the area of the present Grinkle Mines (Fig. 2). Where mined, the Oolitic ore ranged from 2 to 4 feet in thickness and was of good quality, yielding about 35 per cent. of iron. But it diminished both in thickness and value westward, and proved worthless west of a 33 ft.-fault (shown on the *Six-inch* Geological Survey map, Yorks, Sheet 19). The general character and variability of the Dogger in this area are brought out in the following particulars (from the 'North Cleveland' memoir, pp. 41-2):—

Section in the cliff just north of Runswick.

	Ft.	in.
Ironstone, hard and compact	0	4
Sandstone, ferruginous	1	0
Ironstone, very hard	0	7
Ferruginous oolitic concretionary sandstone	1	6
Ironstone	0	2
Sandstone, ferruginous	1	0
Sandstone, with ironstone nodules ... ... on Alum Shale	4	0

Section at an old adit in the cliff at Rosedale Wyke (Port Mulgrave).

Hard stone (good quality)	1	0
Ferruginous marl	2	3
Hard stone	0	3
Pebble-bed	0	2
Grey stone	0	3
	3	11

Section inland, below Low House, Rousby.

Impure ironstone	5	0
Shale	2	0
Ironstone dogger (fossils)	0	6
Shale	1	0
Dogger band ... ... on Alum Shale.	0	6

Section inland, Rousby, about 100 yards S. of last section.

Sandy ironstone, with nests of shells	3	0
Shale	3	6
Dogger band	0	3
Shale	1	0
Dogger band ... ... on Alum Shale.	0	3

[1] Owing to the adoption of the local name 'Rosedale' for this mine it is liable to be confused with the more important Rosedale Mines near Pickering. The localities are, of course, widely apart.

Farther east, in the ground around Kettleness, the ferruginous Dogger is generally thicker, but includes more sandstone, which renders most of it valueless as an ore. Extensive trials, both by borings and shafts, were made here a few years ago for the Skinningrove Iron Company, and proved that the deposit was too patchy and variable to be worth mining. The following is a section from this area given in the 'North Cleveland' memoir, p. 41:—

Section in trial-hole at Cat Beck, Kettleness.

	Ft.	in.
Typical 'dogger,' very ferruginous sandstone; pebble-bed	4	0
Shale, ferruginous	1	6
Ironstone of good quality	0	5
Ferruginous sandstone (or siliceous ironstone) with pebble beds	4	0
Ironstone, with jet fragments	1	2
Ferruginous sandstone (or siliceous ironstone) ...	2	6
Shale	0	11
Ironstone, full of pebbles	0	5
Ironstone, hard and of good quality	0	8

West of Staithes the Dogger is exposed in the high cliffs near Boulby and contains some workable ironstone in places. The following sections were seen recently at the Boulby Mine:—

Section in 'Quarry Drift,' Boulby Cliff.

	Ft.	in.
Soft shale		—
Ironstone with band of small nodules at base ...	4	3
Alum shale		—

Section at mouth of 'Bank Brow Drift', Boulby.

Shale		—
Good ironstone	2	0
Blue shale	1	0
Ferruginous shale and imperfect ironstone	0	6 to 0 8

In the interior west and north-west of Boulby, over the area in which are the chief mines in the Main Seam, the Dogger band has nowhere been found to be worth working, though generally containing thin ferruginous bands and nodules (for details *see* 'North Cleveland' memoir, pp. 42-5).

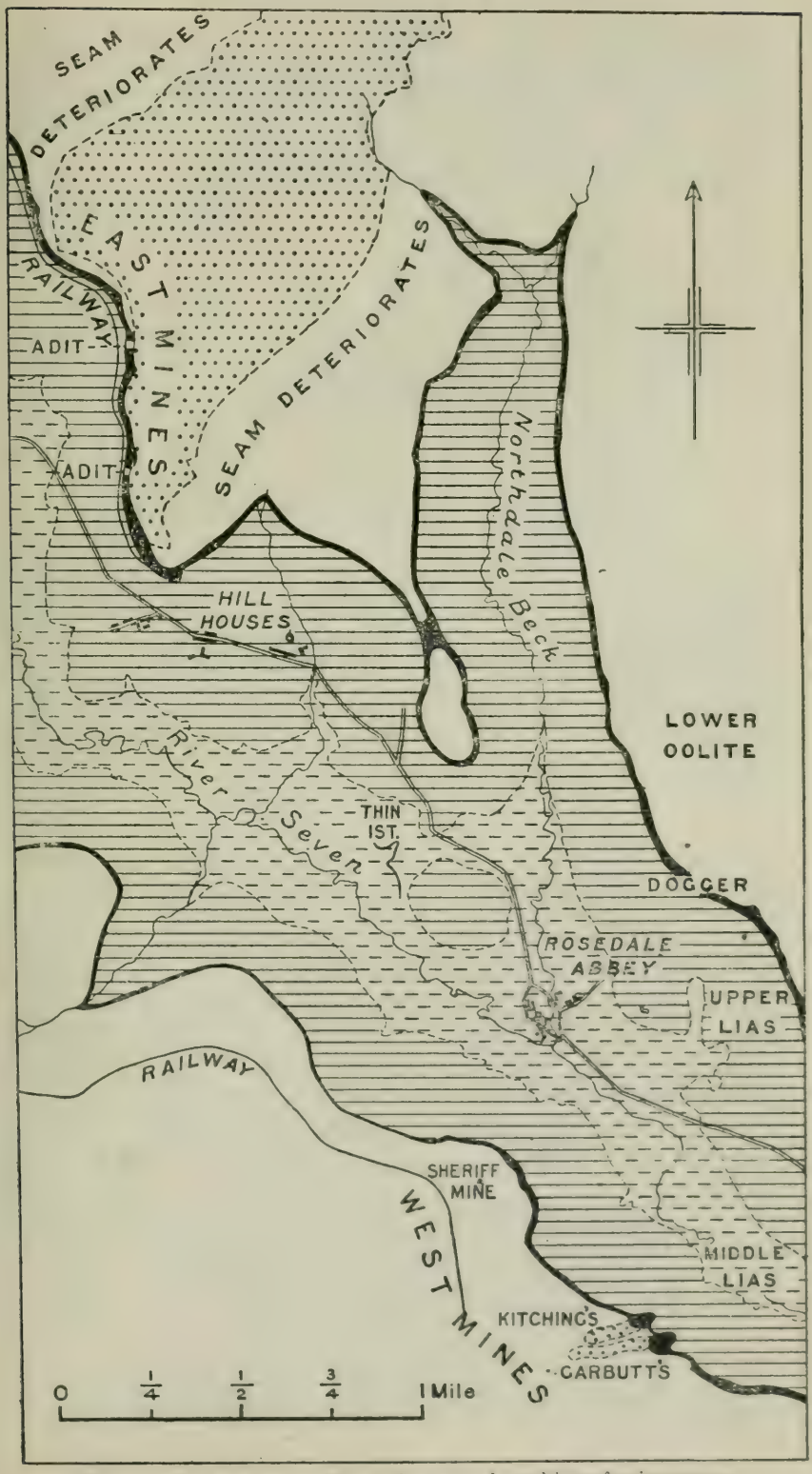
(2) The most important known development of the seam is in the interior at Rosedale, 10 miles N.W. of Pickering, where the Dogger surrounds an inlier of Lias which forms the fertile valley

of the Seven River, surrounded by high barren moorlands (Fig. 7). About midway in this inlier the Dogger on both sides of the valley becomes highly ferruginous and has been extensively mined. One of the mines on the east side of the valley is still producing, as described below, but those on the west side, though at one time rich producers, were suspended many years ago, on the exhaustion of the main ore-deposits. On both sides, ironstone occurs as a workable regular bed, but the most valuable ore-bodies were two exceptional masses of magnetic stone in the West Mines, that filled narrow channels or troughs cut in the Alum Shale. These masses, known respectively as 'Kitching's Deposit' and 'Garbutt's Deposit' lay close together and nearly parallel, as shown in Fig. 7; they were about 70 feet thick in the centre and ran for about $\frac{1}{4}$ mile into the hill, covering an area between 5 and 6 acres in extent. They were quarried at the outcrop, and afterwards mined to their termination. It is estimated that they yielded between the years 1857 and 1880 over three million tons of ore, mostly of high quality (*see* Analysis, p. 60).

In spite of the wide area of the same belt explored on both sides of the valley in mining the more regular seam, and the further exploration by borings and trial-levels outside the mined ground, no other pocket of this kind has yet been discovered, though the local conditions seem not unfavourable for similar occurrences in other places. Local erosion at the base of the Dogger is visible in many parts of the outcrop in Cleveland, and has occasionally resulted in somewhat similar channelling of the Upper Lias, though in no other known case is the channel filled with iron-ore. The cliffs on the east side of Whitby show a section, described and figured in 'North Cleveland' memoir, p. 39, across a sharp hollow in Upper Lias filled in with sandstone; and on the west side of Bilsdale about a mile S. of Wain Stones a similar hollow is filled in with fossiliferous limestone ('Eskdale, Rosedale,' etc. memoir, p. 25). In the deeply dissected country northward from Rosedale to Eskdale, and westward to the edge of the hills, the outcrops of the Dogger are so frequent, and the interspaces between the valleys so narrow, and in some places so well explored, that there is not much chance for the discovery of new ironstone pockets in this quarter; but to the east and south of Rosedale, where the Dogger is deeply covered by higher strata, there is still a possibility that rich patches may be hidden. The few borings of which we have record in these areas (*see* pp. 42-4) have revealed nothing of promise, but they are at wide intervals, and the Rosedale pockets were of such limited dimensions that there is still a chance of buried ore-bodies of similar size remaining to be discovered by a lucky hit or by a close-set series of borings. But the search for pockets of this kind under deep cover is bound, of course, to be highly speculative. It is noteworthy that in a boring under Cross Cliff, in the Hackness district, over 11 miles S.E. of Rosedale,[1] the Dogger was found still to maintain its ferruginous character, which tells in favour of the possibility of local concentration of iron analogous to that of Rosedale under any part of the intervening high moorland country.

[1] The record of this boring is not at present available for publication.

FIG. 7.—*Sketch-map of the mining area in Rosedale.*



The stippled area marks the underground workings for ironstone.
The black line indicates the outcrop of the Dogger.

Apart from the pockets of magnetic ore, the ordinary stratified Dogger Seam was worked in the Rosedale West Mines, and in the adjacent Sheriff Mine, along about a mile of the outcrop, and was followed into the hill until the ironstone became too thin and poor for profitable extraction.

Section of the Dogger, west of Rosedale village.

	Ft.	in.
Yellow shale (roof)	—	
Ferruginous sandstone	1	11
Dark sulphury shale	1	3
Greenish sandy shale	0	6
Dark shale	0	6
Ironstone	8	0
Shale (floor)...	—	

Near Sheriff Pit.

Freestone (roof)..	—	
Sandy ironstone	10	0
Shale	8	0
Soft brown ironstone	0	6
Strong brown ironstone	3	3
Blue-gray ironstone	4	0
Brown and blue stone	5	3

The sandy upper bed was worked only at the outcrop, but the ironstone below was followed for a short distance under the hill, where it was found to thin out in all directions.

The East Mines, 2 miles N.W. of Rosedale village, have covered an area of about 550 acres and are still in operation (1917), but the known reserves of workable ore are now small. The section in the mine is variable; in the central part it was generally as follows:—

General Section in East Rosedale Mine.

	Ft.	in.
Shale	4	6
Dogger	1	0
Ironstone	7	0
'Belemnite' [useless stone]	20	0

At the northern edge of the mined area the ironstone dwindles to less than 3 feet, and is poor in quality; to the south and east also, the stone has proved to be not worth working, and the same conditions prevail, as proved by borings and trial-drifts, throughout the rest of the spur between the main valley and its branch, Northdale (*see* Fig. 7).

The following is a section of the Dogger at the East Rosedale outcrop (from 'Eskdale, Rosedale, etc.' memoir p. 26).

Section in quarried face at Moor Hill.

		Ft.	in.
Carbonaceous shale and rubbly sandstone		10	0
Dogger	Sandstone soft, fine-grained, with white specks ...	9	0
	Hard blue very micaceous shale (very like Lias) ...	4	8
	Ironstone, tough and poor, with white nodules; often left as roof in the mine	1	0
	Ironstone, fossiliferous, oolitic, rather poor	3	0
	? (hidden)	2	0
	Ironstone, very poor and soft, full of casts of *Belemnites*—the 'Belemnite' of the miners ...	7	0
	Ferruginous sandy shale with casts of *Belemnites* ...	7	0
Alum Shale		—	

The portion bracketed on the right is the workable band of the mines. It is stated that a lenticle of magnetic ore, up to 14 inches thick, formed part of the seam in the older workings. (*See* Analysis, p. 60.)

Farther north in Rosedale and in Farndale, the valley next westward, attempts to mine the Dogger as an iron-ore have been unsuccessful.

Other Ironstones of the Yorkshire Oolites.

Several ferruginous bands occurring in the Yorkshire Oolites above the Dogger were used in early times as a source of iron. Of these, the following list and comments are given in 'The Jurassic Rocks of Britain, vol. i, Yorkshire' *Mem. Geol. Surv.*, 1892, p. 434:—

Kellaways Rock ...	Upper part. Along the coast, Danby Moor, etc.
Cornbrash	In Newton Dale, Rye Dale.
Upper Estuarine Series	Irregular bands of granular ironstone. Coast, Fylingdales Moor.
Grey Limestone ...	Impure bands. Eller Beck.
Eller Beck Bed ...	Goathland, Egton Grange, Ingleby Greenhow, Snilesworth Moor.

"Many of the thin, and generally very impure, beds mentioned in this list were in ancient times worked either by the monks or the older inhabitants of these hills, in numerous shallow pits near the outcrop, as at Dry Heads, Killing Pits, Holey Intake, Danby Moor, and other places,[1] which have been supposed by antiquarians to be the remains of "Ancient British Settlements." The ironstone obtained from these shallow workings was smelted in the primitive open hearth or blomary, the evidence of which remains in the heaps of scoriæ, called on the Ordnance Map "Cinder Hills," which may be seen at Julian Park near Goathland, along the valley of the Esk, at Rievaulx Abbey, and elsewhere."

The beds above referred to are all too thin or too poor to have any value under present conditions, or to be reckoned as potential reserves. They are shortly dealt with in the following notes; fuller information, if required, can be obtained from the 'Sheet memoirs' of the Geological Survey (*see* List, p. 62).

Eller Beck Bed.—This is a fossiliferous marine band occurring in the Estuarine Oolites, usually at about 100 feet above the top of the Lias. It consists mainly of sandstone and shale, more or less ferruginous and generally containing ferruginous nodules and thin tabular lenticles of ironstone. It is traceable over the greater part of Cleveland, and becomes more ferruginous inland south of the Esk and Leven valleys, and in this quarter often includes fairly persistent bands of oolitic ironstone ranging from an inch or two to over a foot in thickness. In a few places the ironstone expands sufficiently to have encouraged exploration in recent times, but no permanent working has been established. In Wintergill at the head of Glaisdale, where the Eller Beck Bed

[1] "Ayton Forge, near Hackness, which gives its name to this part of the Derwent valley, was worked near the commencement of the present century. *See* Young, 'Hist. of Whitby,' p. 819. This forge was working in 1788. *See* Marshall, 'Rural Economy,' p. 276."

attains its greatest known thickness and includes an exceptional development of ironstone, the following section was measured[1]:—

Eller Beck Bed at Winter Gill.

	Ft.	in.
Very hard close-grained sandstone containing fragments of soft jet and other carbonaceous matter.	4	0
Ironstone, sandy and impure	1	0
Ironstone, dark brown, oolitic, slightly magnetic; fossils extremely rare.	6	0
Calcareous and ferruginous stone, with a few small fossils...	2	0
Hard flaggy micaceous white sandstone, passing gradually downwards into a sandy shale.	20	0
Sandy marl	1	5
Dense limestone, apparently unfossiliferous	0	4
Argillaceous micaceous shale, much resembling the shales of the Middle Lias.	5	0
Ironstone, with abundance of the characteristic *Pholadomya* and other fossils.	1	0
	40	10

With reference to the old workings at Winter Gill, it is stated (*op. cit.*) that—

"The ironstone varies much in thickness, reaching 13 ft. at the shaft, but changing so fast that it cannot be depended on. It probably soon dies out entirely in each direction. An analysis of the magnetic ore by Mr. W. Morgan gives:—Iron 36·78; silica 11·06; alumina 4·96; phosphoric acid 1·68; lime 3·21; magnesia 1·60; sulphur ·33 per cent. Iron in calcined stone 47·00; loss by calcination 22·78 per cent."

Numerous other sections are given in the same memoir, showing ironstone bands ranging from 1 to 2 feet thick. Full analyses are also quoted for two bands, respectively 5 inches and 14 inches thick, occurring in a section in Eller Beck, at Walk Mill Force below Darn Holm (near Goathland Station), showing, in the 5-inch band, iron in raw, 30·52; in calcined, 39·89; loss by calcination, 23·50; and silica 21·70 per cent.; and in the 14-inch band, iron in raw, 25·40; in calcined, 31·51; loss by calcination, 19·20; and silica, 30·70 per cent.

It is also mentioned (*op. cit.* p. 32) that "above Post Gate Hill [in Glaisdale] the Eller Beck Bed has been tried at two places for ironstone: the easterly hole has fallen in, but the westerly one shows shale with three rows of ironstone." It is further stated (p. 33) that the incline under Burton Howe [S.E. of Ingleby Greenhow] "was originally made to work the ironstone in this bed, and it is evident that it must have been somewhat thicker at the outcrop to have warranted such an outlay." The section given shows only 9 inches of ironstone at this place. An analysis of the seam at Ingleby quoted in 'Jurassic Rocks, vol. i, Yorkshire' (p. 443), gives—iron, 36·95; silica, 7·37; lime, 3·32; phosphoric acid, 1·36; with other particulars.

Farther to the south-west, on Snilesworth Moor (1-inch Sheet 42, New Series) around the headwaters of the River Rye, the ironstone of the Eller Beck Bed has again attracted attention and has

[1] 'Geology of Eskdale, Rosedale, etc.' (*Mem. Geol. Surv.*), 1885, p. 31; also in Jurassic Rocks of Britain,' vol. i, p. 198.

been tested at several places. An inlier of the bed in Blow Gill [' Parci Gill ' on later edition of the six-inch Ordnance Map] "consists of thin flaggy sandstone with 8 feet of shale below. Beneath the shale is a seam of light coloured, somewhat oolitic ironstone" stated to be 2 feet 6 inches thick[1]. In another inlier near the lower end of the same gill, just below Blow Gill Farm, the following section was measured[2]:—

	Ft.	in.
Sandstone	—	
Shale	5	0
Thin ironstone	0	4
Shale	3	0
Ironstone with fossils	0	6
Shale	—	

"There appear to be four or more thin ironstone seams here, but they are not all exposed in one section."

Mr. G. Barrow estimated[3] that there might be 300 acres of good stone averaging about 3 ft. thick in the Blow Gill area, but this estimate appears to be too favourable in view of the sections mentioned above.

Grey Limestone Series.—This is another marine series interstratified with the Estuarine Oolites, usually at 150 to 250 feet above the Eller Beck Bed. The belt consists mainly of calcareous shales and sandstone, with a little ironstone.

"The ironstone, which occurs both in nodules and thin bands, is too poor to be of any commercial value, although it has been tried at one or two places in the interior. There is also a good deal of iron disseminated throughout the series, which gives rise to the bluish-grey colour generally prevalent; along certain lines this appears to become more oxidised, producing a red streaky appearance, which is well shown on the scars south of Scarborough[4]."

Particulars of sections in the series from all parts of the outcrop in Yorkshire are given in the general memoir just quoted, as well as in the various 'Sheet' memoirs; most of the ironstones recorded are between 6 inches and 12 inches thick, and the thickest mentioned is 16 inches (occurring at Hundale Point, Cloughton Wyke). In Eller Beck, near the Whitby road-crossing, where the beds forming the upper part of the series are rather more ferruginous than usual, "a small trial adit was made close to the bridge, with the hope of working them for iron-ore, but they proved too poor for the purpose[5]."

The beds appear to have been worked in ancient times at the 'Killing Pits' on the moors S.W. of Goathland, and in the Leven valley south-west of Spaunton Moor at the place marked 'Smelting Works' on the one-inch map (Sheet 43, New Series).[6] No analyses of the ironstones of this series are on record.

[1] 'Geology of the Country around Northallerton and Thirsk' (*Mem. Geol. Surv.*), 1886, p. 36.

[2] *Ibid.*

[3] 'On the Cleveland Ironstone,' *Proc. Cleveland Inst. of Engineers*, 1879—80, p. 186.

[4] 'Jurassic Rocks, etc.' vol. i, p. 229.

[5] 'Geology of the Country between Whitby and Scarborough,' 2nd ed., 1915, p. 42.

[6] 'Geology of Eskdale, Rosedale, etc.,' p. 39.

Upper Estuarine Series.—Thin impersistent layers of granular ironstone are found occasionally among the shaly beds of this series, as may be seen in the coast-section between Scarborough and Cloughton.[1] They are of no economic consequence.

Cornbrash and Kellaways Rock.—These formations are interlinked; their main outcrop runs from the coast near Scarborough, across the moorlands, to the Hambleton Hills above Northallerton and Thirsk, but with large outliers in Cleveland, on the moorlands north of the Esk valley. The Cornbrash includes a band of hard ferruginous limestone, varying from a foot or two to 7 or 8 feet in thickness. The Kellaways Rock consists mainly of sandstone, ranging from 10 feet to 70 feet or more in thickness, of which the uppermost part is in places ferruginous. Iron appears to have been obtained from both formations in ancient times, but the ferruginous content is too small to allow the rocks to be used as ores for modern purposes.

"At Shaken Bridge on the Rye (above Helmsley) the Cornbrash was some years ago tried as an ironstone, but apparently without much success and the workings were soon abandoned."[2]

"It was also tried several years ago in Newton Dale, but apparently was not thought to be of much value, as the works which are still to be seen in the bank near Skelton Tower were abandoned without the rock being worked to any extent."[3]

No modern trials of the Kellaways Rock for iron are on record. The ferruginous beds in its upper part are displayed in the Scarborough district, particularly in the coast-sections, and in the western escarpment east of Thirsk (for details, *see* Sheet memoirs, and 'Jurassic Rocks, etc.' vol. i, pp. 278-288). No analyses are available, but the rock is probably everywhere high in silica.

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[1] 'Geology of the Country between Whitby and Scarborough,' 2nd ed., p. 45.

[2] 'Geology of the Oolitic and Liassic rocks to the North and West of Malton,' p. 9; *see* also Jurassic Rocks of Britain,' vol. i, Yorkshire, p. 272.

[3] 'Jurassic Rocks, etc.,' vol. i, p. 272.

Tables of Reserves and Output.

Summary of Estimated Cleveland Ore-reserves in 1917.

From the foregoing particulars the probable reserves of iron-ore in Cleveland may be tabulated as follows:—

		Average of Iron in raw stone.	Tons.
Main Seam	In the royalties now being mined	Slightly under 30 % ...	190,000,000
	In the interior ground south of the worked royalties	25 to 30 % ...	150,000,000
Pecten Seam, probably mostly unworkable.		about 26 % ...	40,000,000
Two-foot Seam in northern area, if workable.		30 % ...	50,000,000
Avicula Seam in southern area, if workable.		25 % ...	10,000,000
Oolite or Top Seam, workable parts		30 % ...	1,000,000
			441,000,000

Output of Cleveland Ironstone (including outlying mines of Esk valley, Rosedale, etc.) since 1854.

The figures for the years 1854 to 1881 are taken from the annual 'Mineral Statistics' (*Mems. Geol. Surv.*); for 1882 to 1918, from the continuation of the same, published by the Home Office.

Year.	Tons.	Year.	Tons.	Year.	Tons.
1854 ...	650,000	1876 ...	6,562,000	1898 ...	5,730,413
1855 ...	970,300	1877 ...	6,284,545	1899 ...	5,612,742
1856 ...	1,197,417	1878 ...	5,605,640	1900 ...	5,493,733
1857 ...	1,414,155	1879 ...	4,750,000	1901 ...	5,100,823
1858 ...	1,367,395	1880 ...	6,486,655	1902 ...	5,396,670
1859 ...	1,520,342	1881 ...	6,538,471	1903 ...	5,668,296
1860 ...	1,471,319	1882 ...	6,326,314	1904 ...	5,719,607
1861 ...	1,130,761	1883 ...	6,756,055	1905 ...	5,934,283
1862 ...	1,690,097	1884 ...	6,052,608	1906 ...	6,102,223
1863 ...	2,078,805	1885 ...	5,932,244	1907 ...	6,230,987
1864 ...	2,401,891	1886 ...	5,370,279	1908 ...	6,072,933
1865 ...	2,762,359	1887 ...	4,980,421	1909 ...	6,183,018
1866 ...	2,809,061	1888 ...	5,395,942	1910 ...	6,152,823
1867 ...	2,739,039	1889 ...	5,657,118	1911 ...	6,003,957
1868 ...	2,785,307	1890 ...	5,617,573	1912 ...	5,118,187
1869 ...	3,094,678	1891 ...	5,128,303	1913 ...	5,940,965
1870 ...	4,072,888	1892 ...	3,411,400	1914 ...	5,574,788
1871 ...	4,581,901	1893 ...	4,625,520	1915 ...	4,746,293
1872 ...	4,974,950	1894 ...	5,048,966	1916 ...	4,315,765
1873 ...	5,617,014	1895 ...	5,285,617	1917 ...	4,832,348
1874 ...	5,614,322	1896 ...	5,678,365	1918 ...	4,568,263
1875 ...	6,121,794	1897 ...	5,679,153		

Note.—The earlier series of 'Mineral Statistics' contains many notes respecting the mines, etc., and for some years the output of the individual mines is given. Much information may therefore be gleaned as to some of the old workings, now abandoned. An estimate of the average value of the ironstone per ton at the mines is also generally stated; during the years before 1881, it varies from a maximum of 4s. in 1875 to a minimum of 2s. 9d. to 3s. 3d. in 1879; the average price fell below 3s. in 1886–7–8, but rose above the 4s. level in 1899 and 1900, and after some minor relapses, passed that level again in 1906, and has not since gone below it, being given as 4s. 4d. in 1911, 4s. 8d. in 1912, 5s. 1d. in 1913, with, of course, further increment during the war.

The main point with respect to these tables is that they show the possibility of maintaining the present average output of the district for at least a further 30 years from the existing mines; and that if at the end of this period the conditions are such as to favour the extraction of the thin and deteriorated seams, the same output may be continued for 40 years more.

Lists of Mines and Trials.

Cleveland Ironstone Mines active in 1917.

Name of Mine.	Position of Shafts or Adits. Longitude (West).			Latitude (North).			Company.
	°	′	″	°	′	″	
Ayton	1	5	50	54	29	5	Pease & Partners, Ltd.
Ayton Bank	1	5	30	54	29	25	Tees Furnace Co., Ltd.
Belmont	1	1	46	54	31	14	Bolckow Vaughan & Co., Ltd.
Boulby	0	50	15	54	33	35	Skinningrove Iron Co., Ltd.
Brotton	0	56	25	54	34	13	Morrison & Co.
Eston	1	4	0	54	32	59	Bolckow Vaughan & Co., Ltd.
Grinkle	0	49	43	54	33	5	Grinkle Park Mining Co., Ltd.
Kilton	0	55	35	54	32	34	Bell Bros., Ltd.
Lingdale	0	57	15	54	32	20	Pease & Partners, Ltd.
Liverton	0	54	8	54	33	11	Cargo Fleet Iron Co., Ltd.
Loftus and Whitecliff ...	0	53	47	54	33	45	Pease & Partners, Ltd.
Long Acres and North Skelton.	0	57	22	54	33	18	Bolckow Vaughan & Co., Ltd.
Lumpsey and Carlin How	0	56	20	54	33	31	Bell Bros., Ltd.
Roseberry	1	6	8	54	30	12	Tees Furnace Co., Ltd.
Rosedale East [Top Seam]	0	54	45	54	22	30	Lascelles & Shepherd.
Skelton	1	0	52	54	32	36	Bell Bros., Ltd.
Skelton Park	1	0	14	54	33	14	Bell Bros., Ltd.
South Skelton	0	59	10	54	32	22	Bolckow Vaughan & Co., Ltd.
Spa Wood...	1	0	53	54	31	56	Sir B. Samuelson & Co., Ltd.
Stanghow	0	59	19	54	31	51	Cochrane & Co., Ltd.
Upleatham	1	2	0	54	34	32	Pease & Partners, Ltd.

Cleveland Ironstone Mines exhausted or in abeyance in 1917.

Name of Mine.	Seam.	Longitude (West).			Latitude (North).		
		°	′	″	°	′	″
Blakey, Farndale ...	Dogger	0	57	5	54	22	20
Cliff	Main	0	56	15	54	34	58
Crag Hall	Main	0	54	54	54	33	39
Esk Valley	Pecten & Avicula	0	43	55	54	26	40
Glaisdale	Pecten & Avicula	0	48	0	54	26	10
Grosmont	Pecten & Avicula	0	43	20	54	26	16
Hob Hill	Main	0	59	14	54	34	33
Huntcliff	Main	0	55	20	54	35	3
Hutton	Main	1	4	5	54	30	43
Ingleby	Main, etc. ...	1	4	50	54	26	35
Kildale	Main	1	4	6	54	28	52
Kirk Leatham ...	Main	1	3	35	54	33	34
Normanby	Main	1	8	40	54	32	36
Ormesby	Main	1	9	35	54	32	28
Port Mulgrave ('Rosedale').	Main and Dogger	0	46	0	54	32	50
Rosedale West ...	Dogger	0	52	40	54	20	25
Spa	Main	1	0	15	54	32	8
Swainby	Main	1	14	25	54	24	45
Tocketts	Main	1	2	23	54	33	21
Waterfall	Main	1	1	55	54	32	46

OTHER OLD WORKINGS AND TRIALS IN THE MIDDLE LIAS IRONSTONES IN AND SOUTH OF THE LEVEN AND ESK VALLEYS, referred to in the Memoirs of the Geological Survey.

Site.	*Title of Memoir and Reference.*	
Iburndale, near Ugglebarnby: trial hole ...	'Whitby and Scarbro'	p. 15.
Little Fryup; old workings indicated by slag heaps; seam only 1 ft. thick.	'Eskdale, Rosedale, etc.'	p. 11.
Westerdale, west branch: trial hole ...	,, ,,	p. 13.
Westerdale, shallow old pits on plateau near church.	,, ,,	p. 14.
Bilsdale, old level at foot of Hasty Bank ...	,, ,,	p. 16.
Bilsdale, Stingamire Gill: trial hole ...	,, ,,	p. 16.
Bilsdale, Fangdale Beck	,, ,,	p. 16.
Bransdale: trial hole near north end of Gimmer Bank Wood	,, ,,	p. 17.
Dromonby Hill: trial drift	'Northallerton and Thirsk'	p. 22.
Junction of Raisdale and Tom Gill: trial drift.	,, ,,	p. 22.
Raisdale, in gill south of Breck House: trial hole.	,, ,,	p. 23.
Scugdale: two drifts	,, ,,	p. 24.
Limekiln Bank (main scarp S. of Swainby): drifts in the wood; ironstone thinner than in Swainby Mine.	,, ,,	p. 24.

TRIALS IN THE DOGGER.

1-*inch Sheet* 24. *New Series.*

Locality.	*Remarks.*	*Reference.*[1]
Iburndale, near Ugglebarnby..	Trial hole: rock proved valueless	W. & S., p. 28.
Alum Works in Eskdale, S.W. of Sleights	Dogger 12 ft. thick: often tried as ore without success.	W. & S., p. 28.

1-*inch Sheet* 35. *N.S.*

Raithwaite Gill, 2 miles W. of Whitby	Small adit now obscured: nodular ironstone band, unreliable both in quality and thickness	N. C., p. 39.

1-*inch Sheet* 34. *N.S.*

Cat Beck, Kettleness (*see* p. 27)	Adit	N. C., p. 41.
Kettleness and Goldsborough (Skinningrove Iron Co.'s exploration, *see* p. 27)	Two shafts and several borings.	
Dunsley Dale End, Runswick Bay, near old limekiln	Adit: stone highly ferruginous but too siliceous	N. C., p. 41.
Rosedale or Port Mulgrave ...	Mine and trials (*see* p. 26) ...	N. C., pp. 41-42.
Boulby Mine	Adits (*see* p. 27)	—
Liverton Mine	Level from shaft through Dogger	N. C., p. 44.
Junction of South Leven valley and Kildale	Series of drifts: hard ironstone band of good quality, 10 in.; on ferruginous marly stone with nodules. 5 ft. (*see* Analyses p. 61.)	N. C., p. 44.

[1] Abbreviated references to Geological Survey Memoirs as follows:—

W. & S.—'Whitby and Scarborough,' 2nd Ed. N. C.—'North Cleveland.' N. & T.—'Northallerton and Thirsk.' E. R.—'Eskdale, Rosedale, etc.' Y. & M.—'York and Malton.' For full titles *see* Bibliographical List, p. 62.

Locality.	*Remarks.*	*Reference.*[1]
1-inch Sheets 42 and 52. N.S.		
North end and west side of Vittoria Plantation	Drift: Dogger 20 ft. thick; a ferruginous shelly marl, with about 20 per cent. iron	N. & T., p. 30.
Thimbleby Scar	Trial hole: a few nodules in shale only	N. & T., p. 32.
Atley Bank, near Kepwick	Trial hole: ironstone, 6 in; on ferruginous limestone and shale, 11 ft.	N. & T., p. 32.
Cowesby, near the Hall ...	An old slag-heap probably indicates that Dogger was once worked	N. & T., p. 33.
Kirkby Knowle, main escarpment by Knowle Hill (Sh. 52)	Trial hole: calcareous ironstone, 5 or 6 ft. thick	N. & T., p. 33.
Boltby, close by village (Sh. 52)	Adit: rock like last	N. & T., p. 33.
North of Tang Hall, near Boltby (Sh. 52)	Adit: ferruginous limestone .	N. & T., p. 33.
Cleaves (Sh. 52)	Quarries: worked and burnt for lime, over 20 ft. thick.	N. & T., p. 33
1-inch Sheet 43. N.S.		
Grosmont, immediately above the old ironworks	Trial holes: rock of no value as ore owing to its sudden variations: at one place, 4 ft. thick, with 24 per cent. iron	E. R., p. 21.
Hollin Wood, Murk Esk valley	Trial hole: 15 ft. bluish coarse grained impure ironstone: upper part found to contain 36·7 per cent. iron, but 100 yards off, contained only 19·32 per cent.	E. R., p. 21.
Cat Scar, north of Grosmont...	Dogger essentially a ferruginous sandstone with 23 per cent. iron in lower part	E. R., pp. 21-22.
Glaisdale	Several trials: stone too poor for profitable working	E. R., p. 22.
Glaisdale, Post Gate Hill ...	A series of drifts: ferruginous beds about 12 ft. thick	E. R., p. 23.
Glaisdale, east side of Winter Gill.	Trial	E. R., p. 23.
Oakley Side, north of Esk river	Trial	E. R., p. 23.
Finkel House, Great Fryup ...	Trial: Dogger 25 ft. thick ...	E. R., p. 23.
Farndale, above Church (Blakey Mines)	Several levels driven in hope of obtaining magnetic ironstone of Rosedale: Dogger about 25 ft. thick, but thins rapidly both north and south	E. R., pp. 25-26.
Farndale, Blakey Moor ...	Trial hole: only 5 ft. of poor ironstone	E. R., p. 26.
1-inch Sheet 63. N.S.		
Derwent valley at Kirkham...	Shaft: Dogger 12 ft. thick at 114 ft. depth, worked without much success, rock apparently too poor to pay cost of carriage	Y. & M., p. 12.
Derwent valley, at Mount Pleasant near Castle Howard Station	Shaft: Dogger at 121 ft. 8 in. depth	Y. & M., p. 11.
Derwent valley, Kirkham Park	Adit.	

[1] Abbreviated references to Geological Survey Memoirs as follows:—
N. & T.—'Northallerton and Thirsk.' E. R.—'Eskdale, Rosedale, etc.'
Y. & M.—'York and Malton.' For full titles *see* Bibliographical List, p. 63.

Borings.

North Cleveland.

Borings have been made from time to time to prove the character of the ironstones south of the present mining ground. During the original survey of the district (before 1885), particulars were obtained of borings at Lockwood reservoir, Little Moorsholme, Girrick and three spots farther east in the Easington royalty.[1] In most of these borings the Main Seam was proved at depths of over 600 feet; but the details of the seam as given in the records are mostly untrustworthy and not worth reproducing in view of the more reliable information since obtained by the southward extension of the mines.

During the recent investigation the records of several later borings to the south of the mines were obtained, from which the following particulars bearing on the extension of the ironstones are abstracted. The sites are indicated by the numerals on the Sketch-map Fig. 2. The first two borings are in the Girrick royalty, and we are indebted to Mr. C. Heslop for the records.

(1) Site: 1,100 yards E. of Moorsholme, at junction of Cowclose Lane with old railway; at 525 ft. above O.D.; date, 1912-13; Map, 6-inch Yorks. 18 S.E.

Oolites to 514 ft. [Top Seam not mentioned]; Upper Lias [probably including a few feet of Middle Lias, above ironstone] 258 ft.; Main Seam—"Dogger. 6 in.; Ironstone [Top Block] 2 ft. 5 in.; Shale with traces of iron, 2 ft. 7 in.; Ironstone [Bottom Block] 1 ft. 8 in."; depth to bottom of Main Seam, 779 ft.; below which the boring passed through alternations of shale with thin bands of dogger and ironstone for 26 ft., and through sandy shale and sandstone for 10 ft., ending at depth of 815 ft. (inches omitted.)

(2) Site (1½ mile S. of last), 50 yards S. of Dimmingdale House; at 708 ft. above O.D.; date, 1912; Map, 6-inch Yorks, 30 N.W.

Oolites to 511 ft. [Top Seam not mentioned]; Upper Lias [with Middle Lias above ironstone] 228 ft.; Main Seam—"Ironstone and shale [Top Block], 2 ft. 11 in.; Shale, 2 ft. 11 in.; Ironstone and shale, 6 in. and Inferior ironstone 1 ft." [Bottom Block]; depth to bottom of Main Seam, 746 ft., below which were alternations of shale and ironstone for 23 ft. farther, including an ironstone band 3 ft. thick and another 2 ft. thick. The bottom of the Ironstone Series proper appears to have been reached at 769 ft. from surface, but the boring was continued to 1,275 ft. (inches omitted) through 'dark grey sandy shales' and 'dark grey sandstone' with some ribs of insignificant thickness described as 'ironstone.'

In the last section the Main Seam has almost lost its predominance, while the lower seams are strengthened, thus showing a passage to the conditions found at Grosmont in the Esk valley (pp. 20-24). The boring must have passed through the whole of the Middle Lias and the greater part of the Lower Lias, but unfortunately there is nothing in the record enabling us to identify the horizons. A fault of about 25 feet throw, marked on the Geological Survey Map (Sheet 34 N.S.), runs close by the site of the boring and may account for the diminished thickness of the Upper Lias indicated by the record.

[1] The sites of several of the borings are shown on the published One-inch Geological Map, Sheet 34. Details of the Girrick boring are given in "Explanation of Horizontal Section, Sheet 131" (*Geol. Surv.*), pp. 4-5, and of a boring on Barnaby Moor, to 606 ft., in "Expl. of Hor. Sec., Sheet 132." p. 5.

COMPOSITION AND ANALYSES OF THE MAIN SEAM IN BORINGS IN THE KILDALE DISTRICT. (*See* Sketch-map, fig. 2, p. 15.)

	Borehole No. (*see* Fig. 2.)	Height above O.D.	Depth to base of Main Seam.	Components of Main Seam.	Thickness.	Analyses. Iron in raw stone.	Iron in calcined stone.	Silica.	Lime.	Sulphur.
		Ft.	Ft.		Ft. In.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
In Sleddale.	3	745	225	Top block	2 3	26·71	34·68	13·49	7·20	·30
				Shale	1 2	—	—	—	—	—
				Bottom block	1 11	32·41	44·76	7·24	6·20	·14
	4	698	267	Top block	2 5½	26·65	35·08	12·52	7·76	·15
				Shale	1 7	—	—	—	—	—
				Bottom block	1 5	27·45	35·76	15·09	6·10	·20
	5	685	200½	Top block	2 5	27·55	36·99	11·79	8·42	·09
				Shale	2 5	17·00	19·42	31·60	2·80	·65
				Bottom block	1 1	29·30	38·99	13·20	5·50	·25
	6	667	240	Top block	2 1	25·50	34·38	11·90	9·07	·09
				Shale	1 10	12·45	13·83	36·32	4·20	·78
				Bottom block	1 7	27·50	35·94	15·43	4·26	·22
	7	603	204	Top block	2 5	24·47	32·86	12·39	·33 [?]	·49
				Shale	1 5	6·30	6·85	48·90	·15 [?]	1·301
				Bottom block	2 0½	19·78	24·42	22·64	·80 [?]	·308
	8	575	216	Top block	1 11	23·15	30·54	14·42	9·77	·23
				Shale	2 5	2·70	2·93	54·50	1·45	1·60
			-	Ironstone and shale mixed	1 8	14·10	18·08	33·72	7·05	·82

	Borehole No. (*see* Fig. 2.)	Height above O.D.	Depth to base of Main Seam.	Components of Main Seam.	Thickness.	Analyses.				
						Iron in raw stone.	Iron in calcined stone.	Silica.	Lime.	Sulphur.
		Ft.	Ft.		Ft. In.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
In Loundale.	9	663	120	Top block	2 2	24·87	33·29	11·95	10·00	·089
				Shale	1 4	—	—	—	—	—
				Bottom block	1 6	23·13	27·31	20·87	5·57	·13
	10	628	132	Top block	2 7	29·66	38·40	15·44	7·22	·17
				Shale	1 5	—	—	—	—	—
				Bottom block	1 5	33·18	43·51	14·29	6·85	·16
	11	627	163	Top block	2 1	26·32	36·08	11·49	9·55	·26
				Shale and dogger	1 11½	—	—	—	—	—
				Bottom block	1 1	30·35	41·29	10·15	6·15	·12
	12	605	165	Top block	2 2½	28·32	38·43	10·45	7·85	·15
				Shale	3 0	22·02	26·42	24·29	4·14	·36
				Bottom block	1 0	29·93	39·90	11·07	5·00	·28
South side of Kildale.	13	632	130	Top block	2 2	24·22	32·70	12·20	9·52	·15
				Shale	2 0	3·00	3·21	55·30	1·40	2·00
				Bottom block	1 2	22·77	28·58	22·43	3·67	·58
	14	713	77	Top block	2 0	25·02	33·50	11·72	8·95	·26
				Shale	1 10½	—	—	—	—	—
				Dogger and shale	0 6	28·30	38·50	12·55	5·50	·48
				Shale	0 2½	—	—	—	—	—
				Ironstone	0 5½	28·00	38·67	9·40	8·20	·38
				Shale	0 5	—	—	—	—	—
				Shale and ironstone	0 4	25·60	32·53	15·15	2·80	·35
				Ironstone	0 4	28·50	38·05	11·90	5·30	·14

In the Kildale district, the conditions of the Main Seam between its outcrop in the valley of the Leven and the mined ground to the north have been proved by a series of borings, for particulars of which we are indebted to Mr. J. J. Burton. The main results are tabulated on pp. 40, 41, arranged in groups according to the geographical positions of borings from N.W. to S.E. in valleys descending from the northern moorland, and in Kildale. These borings show very well the thickening of the shale and the deterioration of the ironstone south-eastward, while the more southerly, Nos. 8 and 14, prove the splitting up of the bottom band.

The composition of the Middle Lias Ironstone Series was again proved in one of the borings through the Oolitic rocks in the Rosedale district given below, over 9 miles S.E. of the above Kildale borings; but owing to lateral changes of the strata, the correlation of the individual seams is hardly possible there.

Rosedale District.

A boring made in 1910 on the Spaunton estate, West Rosedale, for particulars of which we are indebted to Mr. C. Heslop, proved the Lower Oolites (including the Dogger) and the Upper Lias to a depth of 337 feet. Partial analyses were made at intervals of about every foot of the cores drawn[1] below 236 feet, and give interesting information as to the percentage of iron, not only in the ferruginous bands but in the accompanying strata as well. The results may be summarised and tabulated as follows:—

	Strata as described.	Thickness. Ft.	Thickness. In.	Depth from surface. Ft.	Depth from surface. In.	Analyses. Percentages of Iron (with Silica in brackets).
Estuarine Oolites, etc.	Sandstone, fireclay, fakes, etc. [details not reproduced] to	—		236	7	—
	Sandstone with balls ...	7	0	243	7	3·60, 1·30, 4·70.
	Grey fakes	0	3			7·90.
	Hard grey sandstone with balls...	2	2	246	0	19·00, 4·00.
	Grey sandstone	5	7			3·00, 2·00, 6·50, 3·00, 3·90.
	Grey sandstone with balls ...	7	8	259	3	8·70, 2·10, 2·70, 5·50.
Dogger.[2]	Top Seam—					
	Grey Sandstone with balls ...	1	11			32·10 (Silica 19·10).
	Grey Sandstone	0	4			
	Sandstone	1	1	262	7	30·10 (Silica 27·90), 27·30 (S. 25·00).
	Grey Sandstone	12	6	275	1	20·85, 22·90, 22·50, 22·80, 26·60 (S. 37·60), 19·50, 15·00, 8·40 (S. 67·00).
	'Belemnite'?—					
	Fakes and sandstone bands ...	5	6			6·75, 6·00, 5·30.
	Sandstone	1	0			9·00.
	Hard fakes	1	0			13·80.
	Grey fakes	4	0	286	7	13·20, 20·30, 25·50, 18·30.

[1] The length of core drawn varied from nearly the full thickness bored, down to one-fourth of the thickness, according to the character of the rock. The number of analyses is therefore not strictly proportional to the thickness given.

[2] It is possible that the higher beds, up to 236 ft. 7 in. should be classed with the Dogger; but further evidence is required.

	Strata as described.	Thickness.	Depth from surface.	Analyses. Percentages of Iron.
		Ft. In.	Ft. In.	
Upper Lias.	Hard grey flakes	1 0	—	6·80.
	Grey flakes	17 4	—	4·20, 4·90, 4·70, 4·25, 4·60.
	Fakey blaise [blaes]	2 0	—	4·80.
	Light flakes	4 0	—	3·95, 4·10.
	Fakey blaise	26 1	337 0	4·10, 4·90, 4·70, 4·10, 4·50, 4·90, 5·50, 4·90, 4·60.

Three borings were made 17 or 18 years ago to prove the Top Seam on the moorland east of Rosedale, and one of these, already referred to, was carried down to the Middle Lias ironstones. The following information is abstracted from the records, for copies of which we are indebted to Messrs. Pease and Partners.

"*Hamer Moor No.* 1 *Borehole*": site, 700 yards E. of Turnhill; at about 1030 ft. above O.D.; date, 1900-01; map, 6-inch Yorks, 60 N.W.

Estuarine etc. Oolites (sandstone, shale, etc.) to 374 ft. 9 in. *Dogger Top Seam*—Ironstone 3 ft. 9 in., Dogger 5 in., Ironstone 3 ft. 2 in. (analysis of last three items—Iron 11·24 per cent., Silica 59·90 per cent.) and 'Ironstone belemnite, very hard' 6 ft. 9 in.; to 388 ft. 10 in. *Upper Lias*—mostly 'blue shale'—254 ft. 11 in.; to 643 ft. 9 in. *Middle Lias*—'blue shale with dogger balls' 8 ft. 3 in. (? on the horizon of the Main Seam), 'dogger or ironstone' 1 ft. 10 in., 'blue shale' 3 in., 'ironstone, pecten' 1 ft. 2 in. (analysis of the two ironstones—Iron 19·67 per cent., Silica 14·70 per cent.; ? = Pecten Seam); blue shale with two thin dogger bands, 25 ft. 3 in.; 'dogger shale ironstone avicula' 1 ft. 6 in. (analysis of last—Iron 24·60 per cent., Silica 14·30 per cent; ? = Avicula Seam); and 'shale' 5 ft. 3 in., to bottom of boring, at 687 ft. 3 in.

The record is not sufficiently explicit to enable us to determine the exact depth at which the Middle Lias was entered, but it is clear that the boring penetrated this division deeply enough to pass through the horizons at which the ironstone seams are developed in North Cleveland. The correlation of the thin bands of poor stone as the 'Pecten' and 'Avicula' seams is doubtful. The boring shows that in this area the Middle Lias does not contain ironstones of present value.

"*Hamer Moor No.* 2 *Borehole, near Glebe Land*": site, Crook Beck Rigg, at N.E. corner of High Hamer enclosure, 1,300 yards S.W. of No. 1 Borehole; at 950 ft. above O.D.; date, 1900; map, 6-inch Yorks. 59 N.E.

Oolites, down to the Dogger Seam, 280 ft. 10 in. *Upper Lias* appears to have been reached at 299 ft. 4 in. and the boring was continued in it to 327 ft. 6 in., the full depth reached. The beds below 277 ft. 10 in. are described as follows:—'grey sandstone very hard (doggery),' 5 ft.; 'Dogger Seam, Top Seam,' 7 ft. 6 in. (analysis—Iron 17·30 per cent., Silica 50·10 per cent.); 'blue shale,' 6 in.; 'dogger, hard and jointy' 3 ft. 9 in.; 'dogger, dark grey (belemnite),' 6 ft. 9 in. Then follows 'blue shale' [presumably Upper Lias] 9 ft.; 'dogger very hard with veins' [? septarian nodule in Lias] 2 ft. 3 in.; and 'blue shale (alum)' 16 ft. 11 in., to the bottom at 327 ft. 6 in.

"*Hamer Moor No.* 3 *Borehole, near Hamer Beck*": site, 250 yds. S. of Lower Row Mires, about 1½ mile S. of No. 1 Borehole; at 675 ft. above O.D.; date, 1900; map, 6-inch Yorks. 60 S.W.

Oolites, including the Dogger, to 135 ft. 7 in.; *Upper Lias*, 20 ft. 3 in. ?, to 155 ft. 10 in., the bottom of the boring. The record of the strata below

114 ft. 10 in., reads as follows:—"blue shale, 3 ft. 3 in.; Coal, 10 in." [proving that the boring is still in Estuarine Oolites]; "grey sandstone, dogger, 6 in.; Dogger Seam, Top Seam, 4 ft. 8 in., and 2 ft. (analysis of 4 ft. 8 in.—Iron 14·45 per cent., Silica 56·60 per cent., Moisture 2·18 per cent); Dogger, 6 in.; dark grey sandstone (belemnite), 9 ft.; blue shale, 5 ft. 6 in.; Dogger, 4 in."; [the last two items are probably Upper Lias]; "alum shale, 14 ft. 5 in." [certainly Upper Lias].

It will be seen from the analyses that in all three of the Hamer Moor borings the Oolite or Top (Dogger) seam proved to be of no present or prospective value as an iron-ore.

More recently a deep boring referred to on p. 28, has been made in the heart of the Oolite country, in a valley under Cross Cliff, west of Hackness, over 11 miles S.E. of Rosedale. Details of the boring are not available, but it is known to have penetrated the Middle Lias. It also proved that the Dogger was here still of the ferruginous or moorland type, and not of the shaly type seen in the nearer coast section at Peak, south of Robin Hood's Bay.

ANALYSES.

Main Seam.

Analyses of the ore from most of the Cleveland mines were obtained during the recent investigation, through the courtesy of the mine-owners and their staffs; but as similar analyses have been published freely in previous accounts of the field (*see* Bibliographical List, p. 63), including a large number in the Geological Survey memoir on 'The Jurassic Rocks of Britain, vol. i. Yorkshire' (pp. 443-8), it is unnecessary to reproduce them in detail. The average composition of the Main Seam, as determined on wide data by Dr. J. E. Stead, F.R.S., has already been given (p. 12); and it will suffice here to append a digest from the analyses collected, showing the range of variation of the seam in different parts of the field. Some groups of analyses, in which the component bands of the seam have been separately analysed, or in which the vertical column has been tested at regular intervals, in some cases inch by inch, are set out below in tables and diagrams, as they illustrate the bedded character of the ore and the composition of the shaly intercalations in the seams.

It will be noticed from the Sketch-map Fig. 2 (p. 15) that most of the mining properties, particularly the southern group, are of considerable length from north to south, stretching in some cases for two or three miles. The southward deterioration of the seam, therefore, gives rise to important differences of quality in the ore from different parts of the same mine, and it is only by a mixture of the stone that an average product can be maintained. In such mines any particular analysis may, of course, be misleading unless it is known from what part of the mine the sample was obtained, or whether it was a mixture from several parts. The following figures are mostly on the average of the mine.

In stone dried at 212° F., the iron content in the Eston-Upleatham-Skelton belt is 31 to 33 per cent.; in the Spawood-North Kilton-Lumpsey-Loftus belt, 28 to 30 per cent.; in the

Roseberry-Ayton-Belmont-Stanghow-Kilton workings, 26 to 28 per cent.; and in the workings farthest southward, 25 to 27 per cent. The silica percentage increases from about 8 in the northerly to about 15 in the southerly mines, the last-mentioned figure being near the limit at which the stone ceases to be regarded as a serviceable ore. A local method for roughly determining whether a stone reaches ore-quality is—to multiply the iron percentage by 2, and the silica percentage by 3, and to reject the stone as ore if the product for silica exceeds that for iron. This rules out a rock containing 25 per cent. iron with 17 per cent. silica. The lime content is remarkably constant in the Main Seam throughout the workings, varying little from the average of 5 per cent., but is more variable and generally much higher in the Pecten and other lower seams (*see* pp. 54-60). Magnesia is similarly constant between 3 and 4 per cent. Phosphoric Acid does not vary much from 1 per cent., but is slightly in excess in the northern part of the field. Sulphur, on the other hand, tends to increase slightly southward, though varying within narrow limits only, say ·05 to ·30 per cent.; the presence of the thin 'Sulphur Band' just above the Main Seam, which is as far as possible rejected, may explain occasional irregularities in the analyses with respect to this constituent. In the Pecten and Avicula seams the sulphur, as a rule, ranges slightly higher than in the Main Seam. The Manganous Oxide shows irregular variation between ·30 and ·80 per cent.

In most of the analyses made for commercial purposes, only the practically important constituents are determined, while there are considerable differences between individual methods of stating the results. These differences frequently affect the tabulation and comparison of the analyses, and must be borne in mind in dealing with these records. For example, some analyses declare the percentage of iron in the 'stone as received' (*i.e.*, with more or less of the original moisture retained), as well as in the stone 'dried at 212° F.' (*i.e.*, moisture expelled); others state the figures for one of these conditions only; while sometimes, through the omission of particulars in the copy available, there is doubt to which condition the figures refer. With moisture averaging about 8 per cent., there is usually about 2 per cent. more iron in the dried stone than in the raw, but the difference may fall as low as 1 per cent. or rise to nearly 3 per cent.

Another point of consequence is that partial analyses may give only the percentage of 'Siliceous Matter' or 'Insoluble Matter,' which includes some silicates,[1] and is always higher than the 'Silica' percentage when this also is given, the difference varying from under 1 to over 5 per cent., according to the quantity of clayey matter present. In the leaner ores the difference may be large enough to decide the question whether a stone reaches 'ore-quality' or not; and analytical results in which 'Insoluble Matter' or 'Siliceous Matter' alone are given cannot be directly compared with those giving 'Silica' alone.

[1] *See* Dr. J. E. Stead's remarks quoted *ante*, p. 13.

Analyses of the DIFFERENT BANDS forming the MAIN SEAM in different parts of AYTON MINE.
Communicated by Mr. C. Heslop (for Pease & Partners).

(1) Face of drift 111 yds. in from day. Sample No. 3, Nov. 3, 1906. *Analysis by Mr. G. Stephenson.* Section.		Iron in stone as received.	Iron in stone dried at 212° F.	Iron in stone calcined.	Moisture.	Loss by calcination.		Siliceous Matter as received.	Silica.	
						As rec'd.	At 212° F.		As rec'd.	At 212° F.
	Ft. In.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Sulphur band ...	0 3½ ...	32·17	34·30	46·28	6·20	25·90	—	14·25	12·47	13·30
Top block	2 5 ...	24·15	26·00	32·91	7·10	21·00	—	22·20	17·18	18·50
Shale	0 9 ...	21·07	22·40	26·76	5·90	16·30	—	33·21	26·25	27·90
Dogger	0 6 ...	29·26	30·20	40·58	3·10	25·60	—	16·27	12·30	12·70
Bottom block ...	1 3 ...	26·08	27·60	35·38	5·50	22·00	—	20·03	15·78	16·70
Total ...	5 2½ Average	25·09	26·73	33·96	6·10	21·30	—	22·24	17·41	18·55
(2) Samples taken by Mr. Stead, Dec. 7th, 1906.										
Sulphur band ...	0 4 ...	30·03	33·25	45·37	9·95	33·81	26·50	—	10·54	11·70
Top block	2 0½ ...	25·42	27·35	34·31	7·04	25·91	20·30	—	13·94	15·00
Dogger	0 4½ ...	29·36	30·70	41·77	4·35	29·70	26·50	—	9·95	10·40
Shale	0 5½ ...	18·52	19·80	23·08	6·48	19·76	14·20	—	28·06	30·00
Dogger	0 8 ...	24·98	26·30	32·27	5·01	22·58	18·50	—	17·86	18·80
Bottom block ...	1 4 ...	28·05	29·50	39·44	4·90	28·87	25·20	—	11·60	12·20
	5 2½									
Average, excluding Sulphur and Shale		26·48	—	36·09	—	26·62	—	—	13·49	—

(3) Samples from No. 1 Drift opposite No. 30, Stenton, May 19th, 1911. Section.		Iron in stone as received.	Iron in stone dried at 212° F.	Iron in stone calcined.	Moisture.	Loss by calcination.		Siliceous. Matter as received.	Silica.	
						As rec'd.	At 212° F.		As rec'd.	At 212° F.
	Ft. In.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Top block	1 7 ...	24·61	25·90	33·94	4·95	23·70	—	17·67	—	—
Mottled stone ...	0 4½ ...	25·34	26·85	34·11	5·60	21·30	—	19·25	—	—
„ „ and dogger	1 1 ...	26·34	27·40	36·05	3·85	24·00	—	16·73	—	—
Shaly dogger ...	1 2 ...	22·88	23·75	29·21	3·65	18·70	—	29·67	—	—
Bottom block ...	1 2½ ...	27·83	28·90	38·07	3·70	24·10	—	16·65	—	—
	5 5									
Calculated analyses—										
Whole seam		25·35	26·47	34·20	4·21	22·60	—	19·94	—	—
Whole seam, excluding 'Shaly dogger.' 'Shale' 21·54 % of total.		26·03	27·22	35·66	4·37	23·68	—	17·28	—	—

Note.—These analyses illustrate the composition of the Main Seam near where the shale-parting is developed. While the middle Dogger differs from the 'Blocks' in physical aspect, the analyses show it to be equal, and in parts superior, to them in its constituents. It will be observed that the shale-parting in its raw state may contain up to 21 per cent. of iron—only 3 or 4 per cent. less than the Top Block—but with a great excess of Silica. The samples of No. (3) set appear to have been originally drier than those of the other two sets, which slightly affects the comparison.

Series of Analyses showing range of variation in the MAIN SEAM in one of the southern mines.

—	A.		A 1.		B.		C.		D.	
	Top Block.	Bottom Block.	Top Block.	Bottom Block.	Top Block.	Bottom Block.	Top Block.	Bottom Block.	Top Block.	Bottom Block.
Iron in dry stone ...	28·40	29·60	27·20	29·60	27·70	27·80	29·00	27·40	28·40	28·20
,, calcined stone..	36·36	38·59	34·56	39·26	35·06	35·64	37·56	35·26	36·41	36·20
Loss by calcination ...	21·90	23·30	21·30	24·60	21·	22·	22·80	22·30	22·	22·10
Siliceous matter ...	17·50	15·90	18·80	15·20	18·	20·40	16·10	21·00	16·70	18·90

—	E.		F.		G.		H.		J.	
	Top Block.	Bottom Block.	Top Block.	Bottom Block.	Top Block.	Bottom Block.	Top Block.	Bottom Block.	Top Block.	Bottom Block.
Iron in dry stone ...	27·40	28·60	27·10	29·40	28·30	23·80	28·70	27·30	26·80	23·80
,, calcined stone..	35·22	36·96	34·83	38·43	36·42	28·13	37·22	35·	34·27	30·24
Loss by calcination ...	22·20	22·90	22·20	23·50	22·30	15·40	22·90	22·	21·80	21·30
Siliceous matter ...	16·90	20·20	17·60	19·70	15·50	24·70	15·	24·	18·	24·

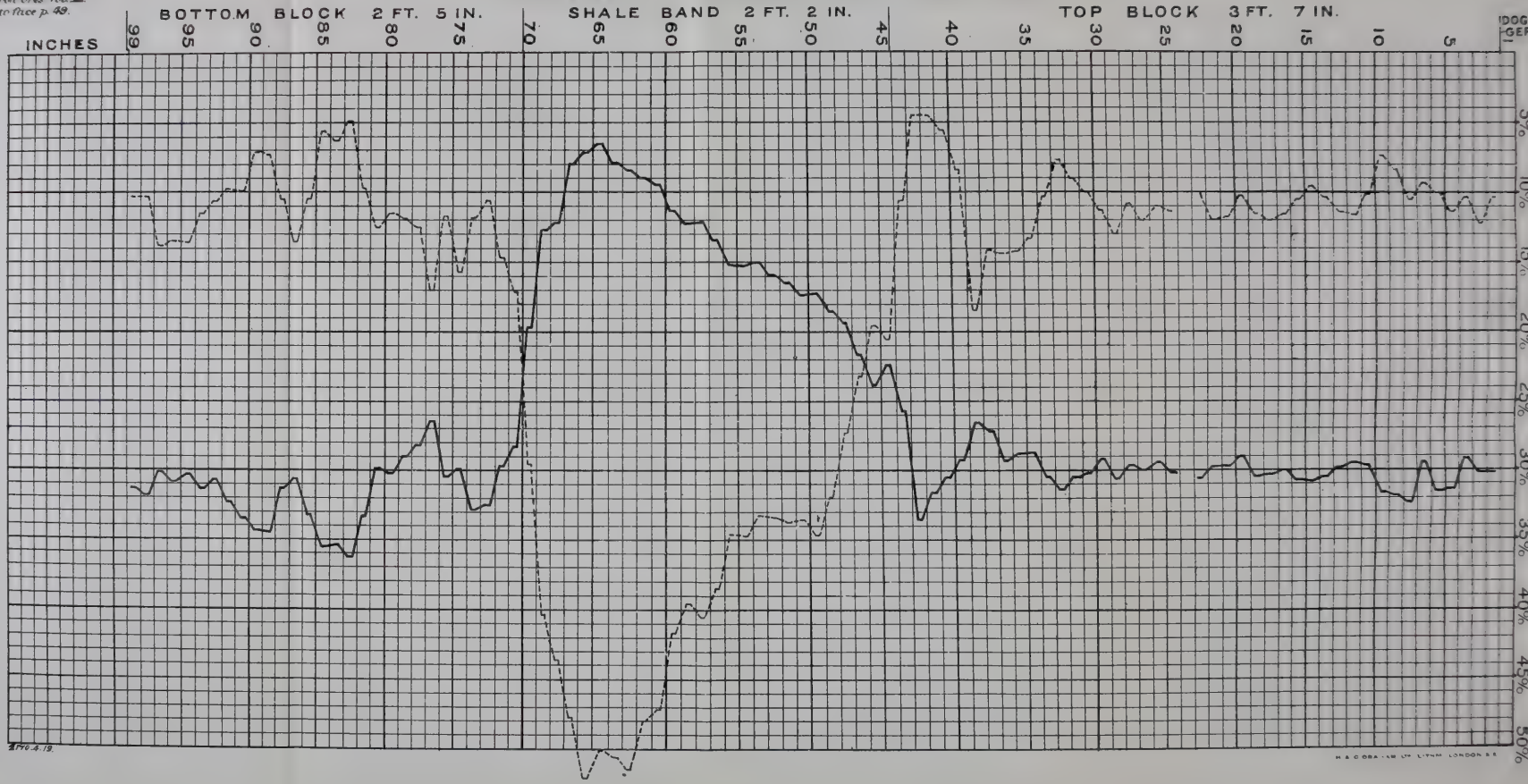
Note.—This series is from one of the mines which had been carried southward to the extreme limits considered to be commercially practicable before the war. It will be noted that the relative values of the two blocks of stone are not constant, but that the Bottom Block is the more variable and undergoes the more serious deterioration from the increase of siliceous matter, which renders some of the stone almost valueless. It will be also observed that the relationship between the increase of siliceous matter and the decrease of iron is quite irregular.

PLATE I.
from Ores Vol. XII to face p. 49.

DIAGRAM OF ANALYSES AT EVERY INCH THROUGH THE MAIN SEAM AT LIVERTON MINES, 1898.

for Averages and Notes, see text, pp. 50-51.

Stone dried at 212° F. Continuous line = Iron. Broken line = Silica.



Serial Analyses of Main Seam, Liverton Mine, at different dates (1869, 1876, 1898, 1901) showing variation.

Communicated by Mr. J. J. Burton.

Samples, September 18th, 1869, taken from where stone was then worked, and reported on, by John Pattinson, Newcastle. Each sample of the rock = about 1 ft.

	Ft.	in.	Sample No.	Moisture.	Iron in dried at 212° F.	Loss.	Iron in calcined stone.
				per cent.	per cent.	per cent.	per cent.
Top Block	4	6	1	10·09	29·65	23·70	38·86
			2	9·50	30·00	21·93	38·42
			3	9·27	30·50	21·73	38·97
			4	8·37	30·05	21·83	38·44
Dogger Block	2	0	5	6·00	26·70	19·80	33·29
			6	4·85	31·65	26·13	42·84
Bottom Block	2	6	7	7·65	29·90	21·20	37·94
			8	7·93	31·40	23·26	40·92
	9	0					

Average analyses of each Block.

"Equal quantities of each sample of each Block were mixed." Analysed in the dry.

	Top Block.	Dogger Block.	Bottom Block.	Average of the whole seam (by calculation).
Oxides of Iron, reckoned as peroxide	per cent. 43·00	per cent. 41·71	per cent. 43·93	per cent. 42·97
Protoxide of Manganese	1·05	1·13	0·70	0·97
Alumina	8·90	10·70	10·90	9·91
Lime	6·04	4·05	4·61	5·20
Magnesia	4·02	4·52	3·93	4·10
Silica	13·60	13·86	12·90	13·46
Sulphur	0·08	0·24	0·07	0·11
Phosphoric Acid	1·19	0·83	1·15	1·10
Loss by calcination	22·20	23·10	22·00	22·36
Metallic Iron	30·10	29·20	30·75	30·08
Iron in Calcined Stone	38·69	37·92	39·42	38·75
Moisture by drying at 212° F.	9·56	5·43	7·79	8·15
In the damp state the ironstone contains—				
Iron				27·63
Loss by calcination				28·68

Liverton Analyses—*continued.*

Samples, April 15th, 1875, taken, and reported on, by J. Pattinson, from southernmost part of mine, from Taylor's dip 638 yards from pit-bottom; full thickness of band in each case. Analyses of WET samples, as taken.

	Ft.	in.	Sample.	Iron.	Loss by calcination.	Iron in calc. stone.
				per cent.	per cent.	per cent.
Top Dogger	0	6	A	24·30	25·23	32·50
Top Block	4	3	B	27·20	29·00	38·31
Band	1	2	C	20·60	20·20	25·81
Middle Dogger	0	10	D	28·20	27·63	38·97
Bottom Block	2	9	E	29·20	27·10	40·06
	9	6				
Average, excluding Top Dogger						37·28
Average, excluding Top Dogger and also Band						38·99

Samples, February 11th, 1898. Analysed at Cargo Fleet Laboratory.

Averages from Analyses tabulated in the Folding-Plate (Pl. I), at every inch at No. 46 S. place, about 370 yards S.E. of Liverton Church. Samples DRIED at 212° F.

	Ft.	in.	Iron.	Silica.
			per cent.	per cent.
Top Block ...	3	7	29·90	10·62
Middle Band ...	2	2	14·15	37·78
Bottom Block ...	2	5	31·49	11·25
	8	2		
Average of Top and Bottom Block			30·54	10·87

6 ft Clean Stone = 73·47 per cent.
2 ft. 2 in. Shale = 26·53 per cent.

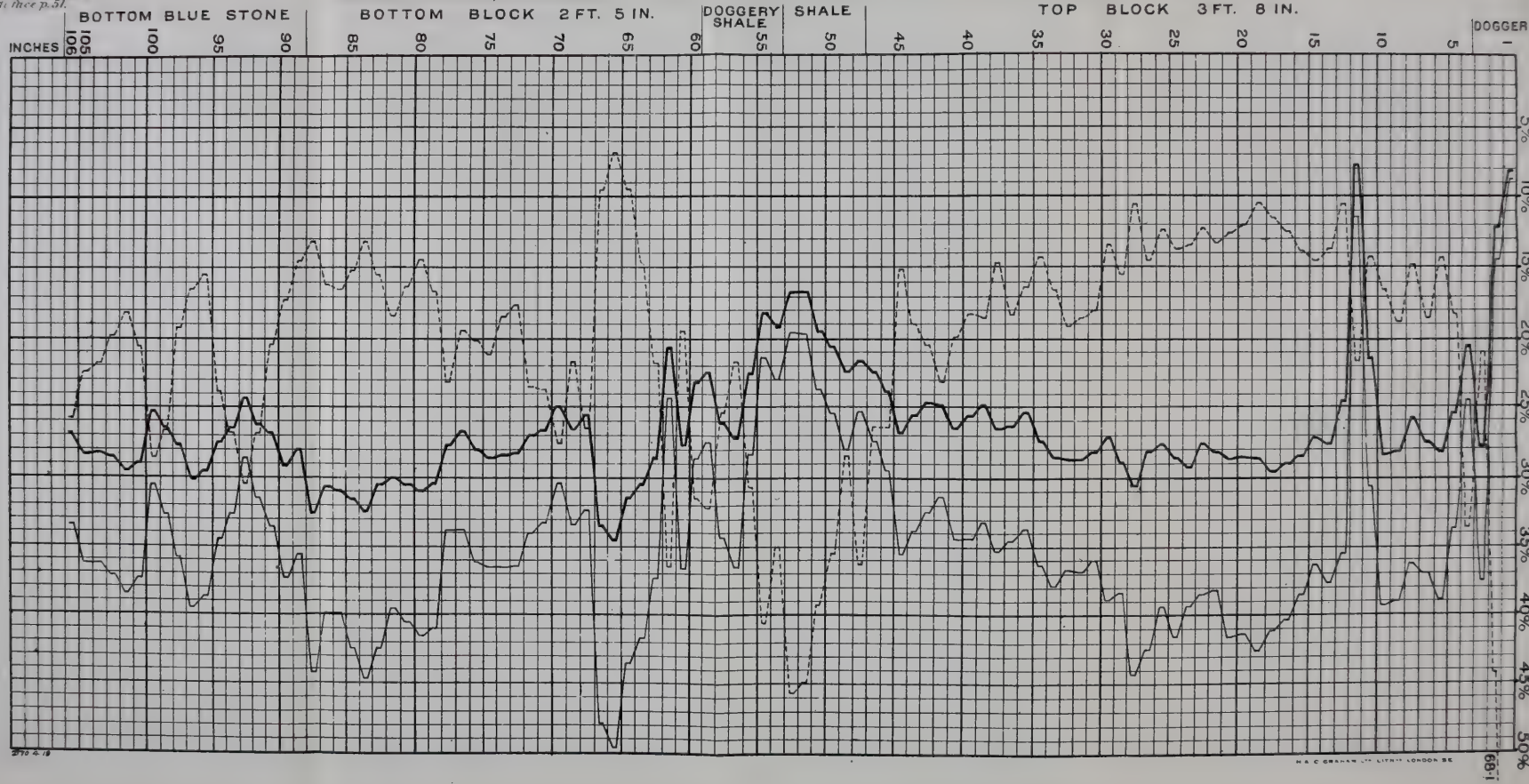
PLATE II

Iron Ores Vol III to face p. 51.

DIAGRAM OF ANALYSES AT EVERY INCH THROUGH THE MAIN SEAM NEAR THE SOUTH-EASTERN LIMITS OF THE CLEVELAND FIELD.

for further description, see text pp. 51-52.

Thick line = Iron in sample as received. Thin line = Iron in calcined stone. Broken line = Insoluble residue.


BOTTOM BLUE STONE
BOTTOM BLOCK 2 FT. 5 IN.
DOGGERY SHALE
SHALE
TOP BLOCK 3 FT. 8 IN.
DOGGER
INCHES
106 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 1
5% 10% 15% 20% 25% 30% 35% 40% 45% 50%

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LIVERTON ANALYSES—*continued.*

SAMPLES, MAY, 1901. Analysed at Cargo Fleet Laboratory.

Analyses of every six inches from columns of stone cut out of farthest south working.

	Ft.	in.	Sample No.	Iron.	Silica.
				per cent.	per cent.
Top Block ...	4	0½	1	27·90	18·44
			2	29·70	13·14
			3	30·40	12·96
			4	30·40	13·72
			5	31·50	13·36
			6	27·60	15·16
			7	30·10	14·16
			8	24·50	28·80
Middle Band	1	10½	... —	Not analysed.	
			9	28·20	22·68
			10	30·70	17·32
Bottom Block	2	4	11	33·80	13·40
			12	30·90	17·30
			13	32·10	18·08
	8	3			

Analyses of each block.

	Top Block.	Bottom Block.
Iron	28·80	30·0
Silica	16·78	17·60
Sulphur	Trace.	Trace.
Loss by calcination ...	23·69	23·39
Iron in calcined stone ...	37·74	39·68

Note.—The mine is situated in an area where the Shale Band expands more quickly after setting in than in any other part of the field, as is indicated on the Sketch-map, Fig. 2, p. 15, by the close approach of the 'One foot Shale' line to the 'Shale line.' This is exemplified by the above four sets of analyses, ranging roughly from north to south, from which it will be seen that the middle Dogger breaks down southward into shale exhibiting a rapid increase of the silica percentage and diminution of the iron.

The inch-by-inch analyses which we have converted into the curve-diagram, Plate I. are particularly instructive in showing the inverse relationship between the silica and iron percentages, which is not, however, absolutely regular. The limits of the shale-band are sharply defined, being nearly at the intersection of the two curves. It will be noticed also, that the further splitting up of the ironstone is foreshadowed, especially in the Bottom Block, by the intercalation of thin bands of inferior quality among the good stone.

The gap at the 24th inch in the diagram is due to an obscurity in the copy of the analyses.

Another series of inch-by-inch analyses, from a section in the south-eastern part of the field, is similarly presented in diagrammatic form in Plate II. In this case, however, the broken line represents 'insoluble residue,' and therefore cannot be directly compared with the 'silica' line of the Plate I. diagram. A third curve is also added showing the percentage of iron in the calcined stone.

This series extends for a few inches higher and lower than the previous set, and thus gives the composition of the worthless rock above the Top ironstone, and of the ferruginous but too siliceous and irregular stone below the Bottom Block. It will be noticed that here the Top Block is of poorer average quality and less regular composition, with more distinct intercalation of shaly material, than in the last section; while, on the other hand, the middle Shale is rather more ferruginous, and less siliceous. This illustrates the manner in which, with the gradual thickening of the strata toward the south-east, as shown in Fig. 5, p. 21, the iron is disseminated through the shales, instead of being concentrated in one bed as it is in the northern part of the field. The limits assigned in the diagram to the 'shale' and 'doggery shale' are those given in the original record, but the analytical results indicate that they should be extended upward for 5 or 6 inches, and downward for 3 inches, to compare with the previous sections.

The following analyses, communicated by Mr. J. J. Burton, show the character of the Ironstone Series in the western escarpment south of the present mining district, where the seams are split up and are hardly recognisable individually. The samples from which these analyses were made were taken at intervals of 6 inches through 8 feet of rock, which probably includes the representative of the Pecten Seam along with the Main Seam (*see* Ingleby Section, Fig. 4, p. 18). The analyses show that, along with some bands of ironstone of fair quality (*e.g.*, Nos. 8, 14, 15), there are other bands of very lean ore (*e.g.*, Nos. 2, 6, 9, 12), and some that are definitely worthless (*e.g.*, Nos. 4, 5, 7, 10). The sulphur percentages are above the average throughout; but the alumina is comparatively low.

Analyses of rock at every six inches from freshly-cut section at end of old workings at Greenhow Bank, near Ingleby Greenhow.

Sample No.	Iron. Fe.	Silica. SiO_2.	Lime. CaO.	Sulphur. S.	Loss on calcination.	Alumina. Al_2O_3.	Magnesia MgO.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	18·8	13·70	13·2	·356	27	5·02	2·89
2	23·2	11·4	10·8	·322	28·3	3·09	5·34
3	25·6	10·2	10·	·391	29·1	2·91	5·34
4	15·9	20·2	8·2	·837	22·1	5·31	2·89
5	3·0	53·7	2·0	1·859	9·5	2·84	1·15
6	20·4	20·9	6·6	·521	21·4	3·93	1·52
7	15·2	29·9	3·4	1·207	20·	3·09	1·52
8	27·2	10·9	6·4	·5	29·1	2·0	4·48
9	23·2	17·9	4·8	·624	22·9	5·18	2·17
10	20·1	20·3	6·	·755	23·3	5·02	2·24
11	22·3	18·4	5·8	·322	23·	5·92	1·73
12	23·4	21·4	5·2	·617	19·8	7·40	1·52
13	22·4	8·0	4·8	·562	27·7	3·85	3·62
14	26·5	8·6	4·6	·521	29·8	4·18	2·96
15	28·8	4·6	5·6	·398	30·2	2·34	3·04
16	24·9	10·2	5·	·603	26·1	5·92	2·17

Shale and Cleaned Ironstone.

In a paper entitled 'The Mechanical Cleaning of Iron Ores,' by the late T. C. Hutchinson, of the Skinningrove Iron Co., Ltd. (*Journ. Iron and Steel Inst.* vol. lxxviii, No. 3, 1908, pp. 38-50), the economy in smelting effected by picking and screening out the shale from the ironstone is dealt with, and is illustrated by a table showing the comparative cost (in 1908) of the materials (ironstone, fluxing-limestone, and coke) required to produce one ton of pig iron from the smelter. Using cleaned ironstone of a stated composition, the cost is given as 40s. $2\frac{7}{10}$d. per ton; small mixed ironstone,—53s. $3\frac{1}{10}$d. per ton; and shale,—67s. $9\frac{7}{10}$d. per ton. Of the enhanced cost, a small part is due to the larger quantity of inferior ore required, but the main part is due to the larger proportion of coke and limestone needed to flux the refractory inferior stone. The composition of the stone and shale (from the Main Seam), determined by analysis, is given as follows:—

—	Cleaned Ironstone.	Small Mixed Ironstone taken out by Belt.	Shale.
	Per cent.	Per cent.	Per cent.
Fe	27·06	23·25	20·94
O	7·74	6·50	6·00
SiO_2	12·50	19·32	26·21
Al_2O_3	9·50	12·50	14·35
CaO	5·00	3·50	3·00
MgO	3·00	3·00	3·00
MnO	0·50	0·50	0·40
P_2O_5	1·25	1·10	1·10
S	0·10	0·65	0·50
CO_2 etc. ...	24·35	19·88	19·00
Moisture ...	9·00	9·00	5·50

'*Sulphur Band.*'

Two partial analyses (without sulphur determination) of the thin pyritous layer at the top of the Main Seam (*see* p. 14) are included in the Ayton series on a previous page (p. 46). We are indebted to Mr. J. J. Burton for the following two partial analyses of this layer giving the percentage of sulphur. It will be seen how necessary is the careful exclusion of this band from the ironstone for the smelter, in order to keep out the detrimental ingredient.

(1)
Iron Sulphide (from Sulphur Band)
Analyst: Arthur A. Street.
March 26th, 1917.

	Per cent.
Total Iron	28·60
Sulphur as Ferrous Sulphate...	45·20
Silica	13·20
Lime	2·80
Phosphoric acid	·52
Total Sulphur	24·58

(2)
Ironstone (Sulphur Band).
Analyst: Ridsdale & Co.,
Middlesbrough.

Dried at 212° F.	Per cent.
Iron	31·10
Sulphur	25·70

'*Pecten*' *and lower Seams.*

The great variability of the Pecten Seam is brought out in the series of analyses which follow. At the northern outcrop, it is in part of workable quality, and has been raised locally to a small extent in the same workings as the Main Seam. This quality is shown in the first of the following tables.

PECTEN SEAM AT UPLEATHAM AND HOB HILL. Communicated by Mr. C. Heslop.

Average thickness of the seam, in seven places, is 34 inches. Analyses done at the Tees Iron Works.

Year.	Samples.	Iron in stone as received.	Iron in stone dried at 212° F.	Iron in stone calcined.	Moisture.	Loss by calcination.	Siliceous matter in stone as rec'd.	Silica.	
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
1911	Upleatham, West ...	28·93	32·75	42·48	11·65	22·90	12·33 [1]	10·33 [1]	
	,, East ...	31·06	33·05	44·90	6·0	26·40	9·77	8·17	
	,, Central ...	31·58	34·00	46·45	7·10	26·80	8·54	6·78	
1913	,, No. 1 ...	27·73	28·30	36·74	2·00	24·54	12·54	11·17	Loss on ignition 22·54
	,, No. 2 ...	28·83	30·25	38·95	5·00	25·99	14·58	12·07	,, 20·99
1905	Hob Hill, No. 1 ...	34·16	37·80	44·73	5·90	15·50	—	10·91 as rec'd. 11·50 dried.	Sulphur, in dried 0·027
	,, No. 2 ...	30·63	35·80	43·44	6·90	24·50	—	9·12 as rec'd. 9·80 dried.	,, 0·050

[1] These figures were reversed in the document copied.

In the middle belt of mines the Pecten Seam is mostly an inferior stone, streaked with siliceous shaly partings, as shown in the two series of analyses represented diagrammatically in Figs. 8 and 9, and also in the Carlin How table below. The character of the seam farther south is demonstrated by some reprinted analyses from the old workings in the Esk valley. Further notes on the composition of the seam in other quarters are included in the details previously given, p. 43.

Analyses of the separate bands forming the Pecten Seam at the Carlin How Mine.

Communicated by Messrs. Bell Brothers, Ltd.

Thickness of band.	Iron in stone as received.	Iron in dry stone.	Moisture.	Silica in dry stone.
In.	Per cent.	Per cent.	Per cent.	Per cent.
7½	25·98	27·70	6·19	18·65
7½	27·42	29·40	6·73	12·02
4	22·38	23·80	5·96	27·31
10	28·55	30·00	4·81	8·23
1½	24·05	25·40	5·28	18·29
8	26·30	27·60	4·69	13·45
3 ft. 2½ ins.				

The records of numerous analyses of the Pecten Seam from the old workings at Grosmont are contained in the last-century literature of the iron-fields, of which the following will serve as an example. It is reprinted from Percy's "Metallurgy: Iron and Steel" (1864), where it is accompanied by the details of a section of the Grosmont mines (*op. cit.*, *p.* 236) in which the Pecten Seam is stated to consist of:—Topstone 10 inches, shale 1 foot 4 inches, Thin-band stone 6 inches, Bottom stone 1 foot 8 inches.

Analysis of Pecten Seam at Grosmont Mines.

By C. Tookey, in Percy's "Metallurgy: Iron and Steel," Table vii, No. 12 (p. 223).

	Per cent.	
Protoxide of iron	34·98	
Protoxide of manganese	0·48	
Alumina	3·20	
Lime	11·96	
Magnesia	4·51	
Carbonic acid	29·20	
Phosphoric acid	1·30	
Water { hygroscopic / combined }	3·30	
Ignited insoluble residue	10·04	containing Silica 8·00.
	98·97	
Iron, total amount	27·21	

FIG. 8.—*Diagram of Analyses of every six inches of rock through the Pecten and Two-foot Seams in Spa Wood Mine, south workings.*

From data communicated by Mr. W. Charlton.

Thick line = Iron; thin line = Lime; broken line = Insoluble Matter; in dried stone.

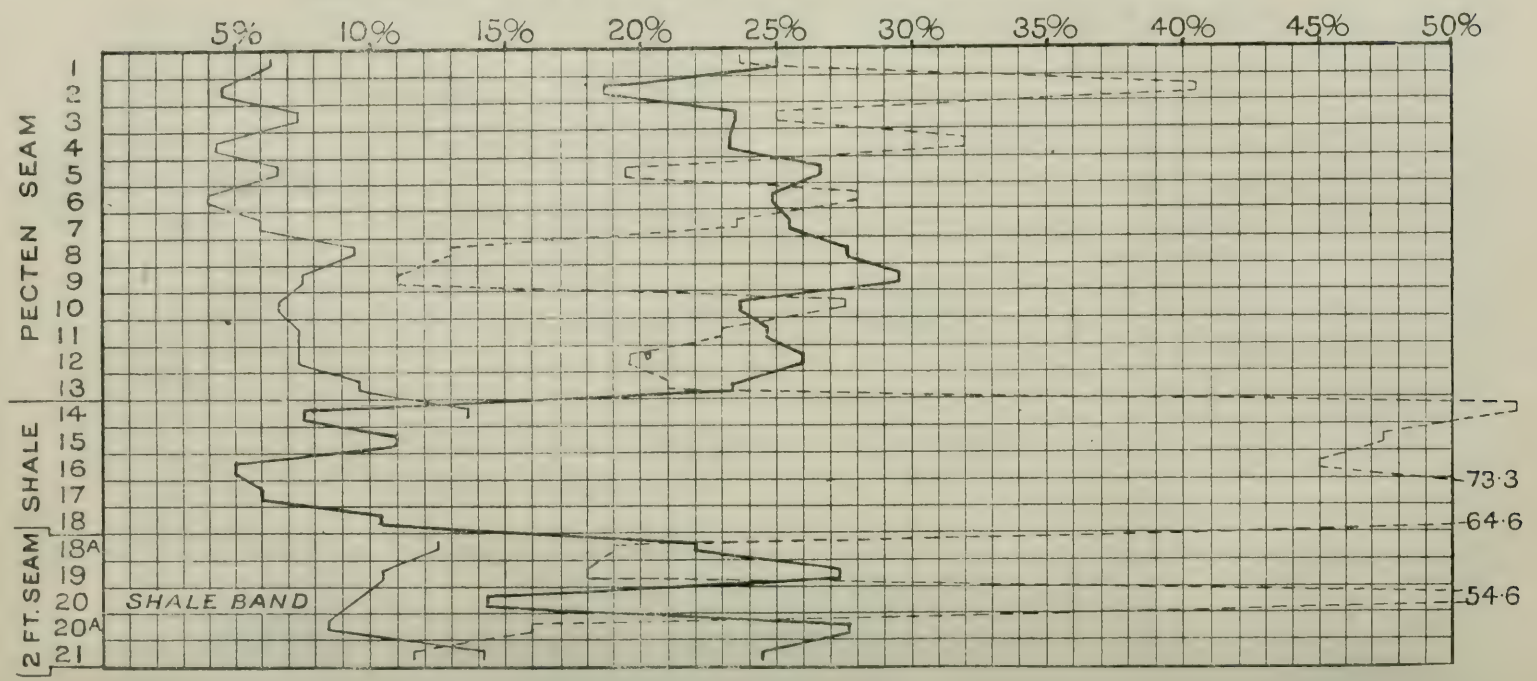
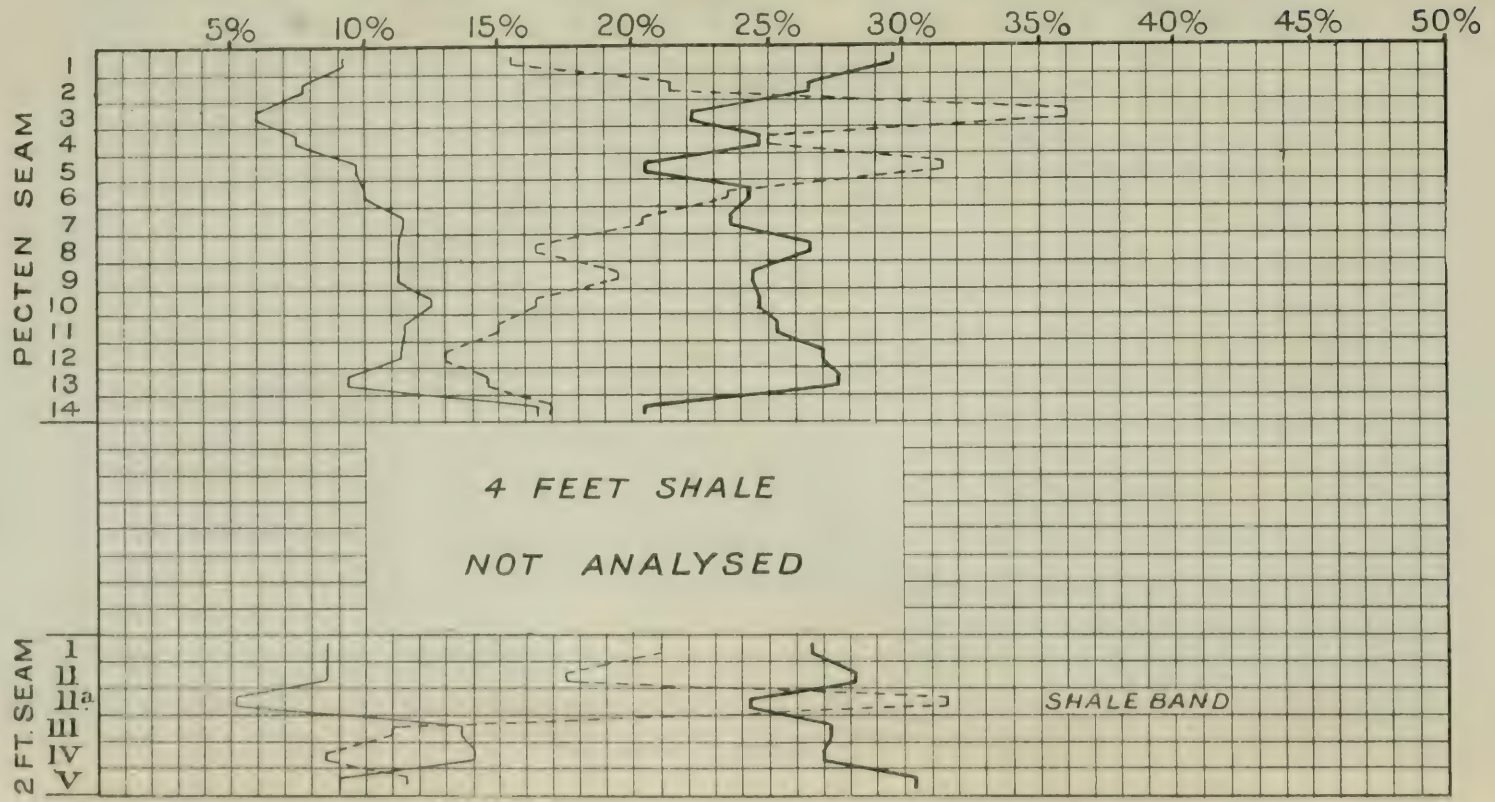


FIG. 9.—*Diagram of Analyses of every six inches of rock through the Pecten and Two-foot Seams in Spa Wood Mine, east workings, in the section shown at p. 22.*

From data communicated by Mr. W. Charlton.

Thick line = Iron; thin line = Lime; broken line = Insoluble Matter; in dried stone.



In the later working of the seam at Grosmont, its quality appears to have deteriorated; and was still lower in the old mines higher up the Esk valley, as shown by the following analyses given in 'The Geology of Eskdale, Rosedale, etc.,' *Mem. Geol. Surv.* (1885) pp. 11 and 12.

Analyses of the Pecten and Avicula Seams in the old 'Esk Valley' Mine.

	Pecten Seam. Per cent.	Avicula Seam. Per cent.
Protoxide of iron	32·74	32·87
Lime	10·97	7·82
Silica	9·75	14·52
Alumina	8·36	12·65
Magnesia[1]	4·33	4·81
Phosphoric acid	1·19	0·55
Sulphur	0·30	0·40
Carbonic acid, Water	31·23	27·05
Loss by calcination	27·60	23·40
Iron in dry sample	25·46	25·55
Iron in calcined sample	33·16	33·35

Average Analysis of the "Upper or so-called 'Pecten' Seam" at the old Glaisdale Mine.

	Per cent.
Protoxide of iron	25·17
Peroxide of iron	2·58
Bisulphide of iron	1·62
Oxide of manganese	0·46
Lime	3·27
Magnesia	2·30
Alumina	5·54
Silica	32·71
Phosphoric acid	1·80
Coaly matter	1·33
Carbonic acid	20·80
Water, extraneous	1·27
Water, combined	0·72
	99·57
Iron in protoxide, peroxide and sulphide	23·10
Sulphur	0·86
Loss by calcination	20·98
Iron in calcined stone	28·15

The low quality of this stone, commented on in the memoir quoted, rules it out of present value as an ore.

Two-Foot Seam.

The serial analyses of the Two-foot Seam in the diagrams, Figs. 8 and 9 (pp. 56, 57), illustrate the variable composition of the band, and its deterioration southward. At Roseberry it is reported to give results closely similar to those of the Main Seam; but at Liverton it has been found to contain only about 17 per cent. of iron and to be high in silica. At Brotton where it is 28 inches thick, the stone is of good quality, as appears from the following analyses, for which we are indebted to Messrs. Morrison and Co. It will be noted that the lime-percentage is higher than in the Main Seam, the stone being in this respect akin to the best parts of the Pecten Seam.

[1] Misprinted 'Manganese' in original.

Brotton Two-foot Seam.

(1) Analyses by Messrs. Pattinson & Stead, Middlesbrough—

	Sample, Feb. 21st, 1911.		*Sample, June 11th, 1912.*	
	As received.	*Dried at 212° Fahr.*	*As received.*	*Dried at 212° Fahr.*
	Per cent.	Per cent.	Per cent.	Per cent.
Iron	30·64	38·03	28·48	31·75
Silica	5·45	5·70	10·41	11·60
Sulphur	0·07	0·07	—	—
Moisture	4·34	—	10·29	—
Loss on calcination ...	31·27	28·15	—	—
Iron in calcined stone...	44·58	—	40·41	—
Specific gravity ...	2·96	—	—	—

(2) Analysis by J. & H. S. Pattinson, Newcastle-on-Tyne—

Sample, Feb. 28th, 1911.

Dried at 212° Fahr. Moisture loss 6·48 per cent.

	Per cent.
Iron peroxide	1·71
Iron protoxide	35·61
Manganese oxide	0·37
Alumina	8·35
Lime	10·53
Magnesia	4·03
Potash and Soda	0·18
Titanium and Soda	0·18
Silica	7·75
Carbonic acid	25·25
Sulphur	0·102
Phosphoric acid	1·28
Carbonaceous matter	0·36
Combined water	4·15
	99·852
Metallic iron...	28·90
Phosphorus	0·56
Loss on calcination	26·87
Iron in calcined stone	39·52

At the Carlin How Mine, about 1½ mile S.E. of Brotton, the seam is thinner and can be divided into three lifts, of different quality, as shown by the partial analyses below, communicated by Messrs. Bell Brothers, Ltd.

Carlin How Two-foot Seam.

Thickness of Band.	Iron in dried stone. Per cent.	Silica in dried stone. Per cent.
Top 6 ins.	31·50	9·88
Middle 7 ins.	21·60	7·00
Bottom 8 ins.	19·80	8·15
1 ft. 9 ins.	Average over all, CaO on dry, 22·50 per cent.	

Avicula Seam.

Many analyses of the Avicula Seam from the old workings around Grosmont are contained, along with those of the Pecten Seam, in the early literature already referred to, and it will suffice here to insert a few results obtained during the later period of working, and not previously published. A reprinted analyses of the deteriorated seam in the old Esk Valley Mine has been

given above (p. 58). The four analyses which follow have been selected from a large number placed before us by the courtesy of Mr. Gladstone of Grosmont, and are intended to show the average quality and range of variation of the seam in the most recent development (up to 1913) of the 'East Grosmont' or 'Eskdale' Mine.

Grosmont Avicula Seam.

Analyses made at the Clarence Iron and Steel Works.

No.	Iron in stone as received.	Iron in stone dried at 212° F.	Iron in calcined stone.	Loss in calcination.	Moisture.	Silica.	Lime.	Sulphur.[1]
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	27·39	29·20	37·38	21·88	6·2	12·88	—	0·48
2	24·21	25·60	32·99	22·42	5·4	13·12	8·23	0·57
3	24·03	25·40	32·51	21·88	5·4	12·24	9·25	—
4	23·17	25·00	32·95	24·14	7·3	12·52	9·01	—

[1] In the whole series of analyses the range of Sulphur was from ·32 to 1·46 per cent.

Dogger or Top Seam.

Regarding 'East Rosedale,' the only mine at present working the Dogger Seam, the following analytical particulars of the ore were given in 'Eskdale, Rosedale, etc.,' memoir (p. 26), and may be taken as still fairly representative, though the stone is variable and sometimes falls a point or two lower in iron:—

Iron, 32·70; Siliceous matter, 9·27; Phosphoric acid, 1·64; Water, 6·30; Loss by calcination, 28·30; Iron in calcined stone, 45·60 per cent.

At the abandoned Sheriff's Pit, on the opposite side of the dale, an average of five samples, quoted in 'Jurassic Rocks, vol. i. Yorkshire' (p. 443) gave:—Iron, 38·01 and silica, 12·20 (with other details); but there appears not to have been much stone of this high quality in the mine.

Many analyses of the magnetic ore from the worked-out rich pockets of the West Rosedale Mines have been published. The following, given in the 'Eskdale, etc.' memoir (p. 27), as "the average of a number of analyses of the magnetic stone," will serve as a general example.

West Rosedale Magnetic Ore.

	Per cent.
Peroxide of iron	32·56
Protoxide of iron	25·92
Protoxide of manganese	0·22
Alumina	7·13
Lime	2·84
Magnesia	1·82
Silica	7·03
Carbonic acid	9·38
Sulphur	0·02
Phosphoric acid	1·57
Carbonaceous matter	0·56
Combined water	4·88
Moisture	6·20
	100·13

	Per cent.
Metallic iron...	42·95
Loss by calcination	18·06
Iron in calcined ore	52·42

Three full analyses of the variable Dogger Seam at Grosmont are quoted in the memoir last mentioned (p. 22), showing respectively, Iron 25·50, 17·34, and 31·71 per cent., with Silica 18·12, 23·10, and 8·80 per cent. Further analyses of the same seam at Rosedale Wyke or Port Mulgrave (Iron 32·37, Silica 20·32), and at Raithwaite Gill (Iron 31·06, Silica 34·25), are quoted in 'Jurassic Rocks, vol. i, Yorkshire' (p. 443). Partial analyses of the Dogger at other points are included in the description of borings on previous pages (pp. 42–44).

The following analytical results, showing the composition of a 7-foot band in Kildale, are reprinted from J. Phillips' 'Geology of Yorkshire; Part 1. The Yorkshire Coast,' 3rd ed., 1875, p. 180.

They are stated to be the "complete analyses of the thick bed at Kildale, executed by Mr. Pattison at the Clarence Works on the Tees." From the context it might be presumed that the bed referred to was the Main Seam; but the composition of the 5th and 6th foot, which are practically limestones, and the mention of the phosphatic nodules therein, shows that the results relate almost certainly to the Dogger band, probably in the old Kildale workings mentioned on p. 37 and described in the 'North Cleveland' memoir, p. 44. The separate analysis of the phosphatic nodules, quoted below, is of interest, as showing how greatly they affect the percentage of phosphorus in the band containing them.

	Top foot.	2nd foot.	3rd foot.	4th foot.	5th foot.	6th foot.	Bottom, 7th foot.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Protoxide of iron.	40·50	31·95	33·56	28·28	15·43	14·91	32·01
Peroxide of iron.	2·80	9·50	4·14	8·71	1·30	1·80	2·43
Protoxide of manganese	0·37	0·60	0·55	0·54	0·37	0·37	0·35
Alumina ...	5·43	10·34	9·03	11·57	5·38	6·25	9·23
Lime ...	4·34	3·17	4·48	4·90	29·31	28·00	3·80
Magnesia ...	3·21	3·22	3·21	2·97	2·25	2·60	4·31
Silica ...	9·27	15·47	16·00	18·60	10·17	11·13	15·27
Carbonic acid	28·60	18·80	22·80	17·00	29·60	29·80	26·80
Phosphoric acid.	0·98	1·09	0·94	1·02	2·35	1·92	1·30
Water ...	3·06	5·85	4·71	6·29	2·46	2·43	3·20
Sulphur ...	Not estimated, but a very small quantity.					...	1·12
	98·56	99·99	99·42	99·88	98·62	99·21	99·82
Total Metallic Iron ...	33·45	31·50	29·00	28·10	12·90	12·85	26·60

. . . "The samples of the 2nd, 3rd, and 4th foot were slightly 'weathered' . . . The carbonate of lime in the 5th and 6th foot samples exists as small confused crystals, which are interspersed with a number of pebble-shaped nodules containing a large quantity of phosphoric acid. These nodules varied in size from the size of a pea to that of a chestnut. A number of them were collected and analysed. They contained:—Alumina 27·97, Lime 12·92, Magnesia 0·72, Peroxide of iron 0·70, Protoxide of iron 4·08, Phosphoric acid 28·27, Sulphur 0·52, Carbonic acid 4·00, Soda 0·40, Carbonaceous matter 1·27, Water 2·84, Insoluble in hydrochloric acid 15·60 per cent."

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1854 to 1881. Mineral Statistics (annual volumes), *Mems. Geol. Surv.* Extracts and note *ante* p. 35 (continued annually from 1882 to date as *Home Office Blue-books*).

1856. 'The Iron Ores of Great Britain,' Part I., *Mem. Geol. Surv.* Contains description of Cleveland ironstone, with full analysis by A. Dick. pp. 45-47; 95-97.

Geological Maps of the Cleveland district—

1880–1883. *One-inch Maps.*

Sheet 33, New Series = 103 S.E. Old Series. 'Stockton' (drift edition colour-printed; solid edition, hand coloured.)
,, 34 ,, = 104 S.W. Old Series. 'Guisbrough' ,, ,,
,, 35 with 44, New Series = 104 S.E. and 95 N.W. Old Series. 'Whitby' and 'Scalby' (drift edition, colour-printed; solid editions, hand-coloured).
,, 42, New Series = 96 N.W. Old Series. 'Northallerton" (drift edition, colour-printed; solid edition, hand-coloured).
,, 43, New Series = 96 N.E. Old Series. 'Egton' (drift edition, colour-printed; solid edition, hand-coloured).

1881–1899. *Six-inch Maps.*

Yorkshire Sheet 7. 'Upleatham' (1881; hand-coloured).
,, ,, 8. 'Saltburn' (1888; hand-coloured).
,, ,, 9. 'Boulby' (1878; hand-coloured).
,, ,, 17. 'Guisbrough' (1888; hand-coloured).
,, ,, 19. 'Staithes' (1899; hand-coloured).

The remaining Six-inch Maps of the Ironstone field are not published but manuscript copies are deposited in the Geological Survey Library 28, Jermyn Street, London, for public reference.

1883–4. Horizontal Sections, *illustrative of the Cleveland Ironstone district.*

Sheet 130. From Staithes, through Whitby, across the Vale of Pickering to the Chalk.
,, 131. From Redcar by Upleatham, Danby, Pickering Moor and the Vale of Pickering.
,, 132. From Middlesbrough by Eston, Easby Moor and the Howardian Hills to Brandsby.
,, 133. From Ferryhill across the Tees Valley, Whorlton and Osmotherley Moors to Easingwold.
,, 134. From Cod Beck across Black Hambleton, Rosedale, Egton High Moor to Hawsker Bottoms.
,, 135. From Upsall across Boltby Moor, the Hambleton Hills by Hackness to Gristhorpe Bay.

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General account of the North Cleveland mining district, with details of the seams, comparative sections, etc., and notes on the iron industry.

1892. Fox-Strangways, C. The Jurassic Rocks of Britain, vol. i, Yorkshire.
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CHAPTER III.

IRON ORES OF LINCOLNSHIRE, LEICESTERSHIRE, RUTLAND, NORTHAMPTONSHIRE AND OXFORDSHIRE. (Introduction.)

By C. B. Wedd.

The geology of the district is illustrated by numerous maps and by memoirs of the Geological Survey, to which reference is made below. Of these memoirs "The Geology of North Lincolnshire" (1890) contains an account of the Frodingham Ironstone, with sections and lists of fossils (pp. 21-31), as well as of the Claxby Ironstone (pp. 108-10), of which further details are given in 'The Geology of Lincoln' (1888), also with sections and fossil-lists (pp. 94-6, 102-3), and in 'The Geology of East Lincolnshire' (1887). 'The Geology of Lincoln' farther supplies an account (pp. 36-42), with analyses, of the Northampton Ironstone of Mid Lincolnshire, while 'The Geology of South-West Lincolnshire, with parts of Leicestershire and Nottinghamshire' (1885) describes the Marlstone ore of that part of Lincolnshire and the main Leicestershire ironfield, as well as the Northampton Ironstone of Waltham-on-the-Wolds (pp. 37-42, 45-7, 117-21, with analyses). More recent accounts of these are given in 'The Geology of Melton Mowbray' (1909, pp. 40-9, 55-9, 90-6), and of the Marlstone of the Tilton area in 'The Geology of Leicester' (1903, pp. 30-7). 'The Geology of Rutland' (1875) contains a full description of the Northampton Ironstone of Rutland and parts of Northamptonshire, also noticed briefly in 'The Geology of Part of Northamptonshire' (1860) and 'The Geology of Parts of Northamptonshire and Warwickshire' (1861). 'The Jurassic Rocks of Britain' includes a description of the Liassic Iron-ores (vol. iii, 1893, pp. 300-7) and of the Northampton Ironstone vol. iv, 1894, pp. 493-9), as well as numerous measured sections and other details. Many records of thickness of strata and depth of the ironstones may be found in 'The Water Supply of Lincolnshire' (1904), 'The Water Supply of Bedfordshire and Northamptonshire' (1909) and 'Thicknesses of Strata' (1916).

Among unofficial papers dealing with these ironstones and their geology, mention may be made of:—

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'On the Speeton Series in Yorkshire and Lincolnshire'—G. W. Lamplugh, *Quart. Journ. Geol. Soc.*, vol. lii (1896), p. 179.

General Characters of the Ironstones.

Three iron-ores are now in use in these counties, while a fourth has been worked to some extent in the past and is likely to come into use again. All these ores are bedded oolitic deposits; but their oolitic character may more or less completely disappear on weathering.

The ores in question, with their geological age and general distribution, are:—

Iron ore.	*Geological formation.*	*Distribution.*	
Claxby (or Nettleton) Ironstone.	Lower Cretaceous	N.E. Lincs.....	Not now worked.
Northampton Ironstone.	Inferior Oolite	Mid and South Lincs., Rutland, Northants.	Worked.
Marlstone Ironstone ...	Middle Lias	Mid and S.W. Lincs. and Leicestershire.	
Frodingham Ironstone	Lower Lias	North Lincs.	

These ores differ from one another considerably in composition, and the difference has an important bearing upon the iron-industries dependent upon them. Apart from internal variations in the proportions of constituents from place to place, the general points of difference between the ores may be summarized thus:—

The Frodingham Ironstone contains more than enough lime to make it self-fluxing, and consequently is, for practical purposes, richer in iron than its low percentage of iron implies. On the other hand its excess of lime precludes the use of its whole thickness by itself in the blast-furnace, and since the whole bed is now used, the addition of siliceous (Northampton) ore is necessary. Its percentage of silica and alumina is less than those of the other ores used. It has a small and rather constant amount

of phosphorus and a small amount of sulphur; and it always has a considerable manganese-content, constant within narrow limits. It is essentially a calcareous and manganiferous ore.

The Marlstone ore of Leicestershire and Mid Lincolnshire contains a greater proportion of iron, and on the whole more silica and less lime; but it varies greatly in its actual content of silica and especially of lime. It is usually classified into 'siliceous' and 'limy' varieties according to the amount of weathering it has undergone. Moreover, being worked largely in a highly decalcified state, it is on the whole more porous and holds a larger amount of water than the other ores; so that its iron-percentage is notably increased on drying. It contains little manganese as compared with the Frodingham ore, and its phosphorus- and sulphur-percentages are also rather low.

The Northampton Ironstone, richer in iron than either of the other two, is more siliceous and less calcareous in its unweathered state. It has a low percentage of sulphur, and contains much less manganese, but more phosphorus, than the Frodingham ore. It is always a siliceous ore, while here and there containing more lime than usual.

The Claxby Ironstone, not unlike the decalcified and siliceous form of the Marlstone ore, is less rich in iron than the Northampton ore but, like it, contains much more silica than lime. It is poor in manganese and is regarded as a siliceous ore.

The following table compares the average values of the principal chemical constituents of all these ironstones:—

Raw Ore.	Frodingham Ironstone. 1.	Marlstone Ironstone.[1] 2.		Northampton Ironstone.[2] 3.	Claxby Ironstone. 4.
		siliceous.	calcareous.		
	per cent.			per cent.	per cent.
Iron, in moist ore ...	21·8	25·5	23·7	32·93	27·3
Iron, in ore dried at 100° C.	25·0	33·2	29·4	39·04	32·7
Silica, in moist ore	14·5	12·1	10·9	14·29	20·8
Alumina, do. ...		8·2	7·4	6·18	
Lime, do. ...	15·5	2·9	13·5	3·41	4·2
Magnesia, do. ...	1·3	·6	·7	·34	—
Manganese, do. ...	1·1	·2	·3	·20	—
Sulphur, do. ...	·15	·1	·2	·09	—
Phosphorus, do. ...	·25	·3	·5	·63	—
Moisture	12·8	23·2	19·0	15·48	16·5

[1] Leicestershire. [2] Main Ironfield of Northamptonshire.

Metallurgical Classification of the Ores.

The difference of character between some of these ores has led to a wide difference both in metallurgical treatment and in the resultant metals; but recently the stress of war conditions demanding an increased output of basic steel, has induced changes of practice and a wider production of basic iron for that purpose.

The Frodingham ore, mixed with an appropriate complement of siliceous Northampton ore, yields an iron suitable for steel-making by the basic open-hearth (Siemens) process or by the Talbot process, regarded as a continuous open-hearth process. For, while it contains enough manganese to eliminate sulphur and excessive silicon from the iron, it holds too much phosphorus for acid methods of steel-making, but not as much as is liked for the basic Bessemer process. Consequently the 'white' and 'mottled' grades of iron constituting the main product of the Frodingham blast-furnaces are used there exclusively for making steel by the basic Siemens and Talbot processes. A little forge-iron of good quality and a less proportion of foundry-iron are also produced.

The Marlstone ore of Leicestershire and Lincolnshire, as used in mixture with Northampton ore, and sometimes with farther addition of a small amount of more calcareous ore as ferric lime, contains less silica than the Northampton ore alone, with a low percentage of sulphur and manganese, but a somewhat higher percentage of phosphorus. The mixture is suitable for making good foundry- and forge-irons, still the principal use of the Marlstone ore in the Leicestershire, Nottinghamshire and Derbyshire furnaces. But many ironworks that formerly made these grades of iron alone there, are now producing basic iron for steel-making, and for that purpose are using chiefly a mixture of Northampton and Frodingham ores, while still making foundry- and forge-irons from the mixture of Marlstone and Northampton ores.

The siliceous Northampton Ironstone, formerly sent in large quantities to the coalfields for mixing with the calcareo-argillaceous ores of the Coal Measures,[1] is used in Northamptonshire without admixture of other iron-ore, and tends to produce a somewhat siliceous, phosphoric and fluid metal, relatively free from sulphur and adapted for foundry use in making iron pipes and small castings for which sharpness of detail is required. Under ordinary conditions the product of the Northamptonshire furnaces, commonly mixed with other irons, has made foundry-iron of several qualities and forge-iron. But recent requirements have necessitated a partial change of treatment and the addition of manganese-ore or manganiferous slag, to render the pig suitable for making basic steel, which however is not manufactured in the district.[2] For this purpose the Northampton ore is beginning to be used on a large scale, while foundry- and forge-irons are still produced extensively in Northamptonshire.

Thus a consideration of the ironfields of these four counties, from the point of view of the different ores used in relation to the different kinds of iron produced, suggests a classification into three provinces of iron-production, in each of which the nature of the ore or ores available determines the natural quality and uses of the metal obtained.

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[1] J. W. Judd, 'Geology of Rutland' (*Mem. Geol. Surv.*), 1875, p. 112.

[2] Steel appears, however, to have been made from Northampton Ironstone at the old Towcester Ironworks about 1875. *See* R. Meade, 'Coal and Iron Industries of the United Kingdom,' 1882, p. 553.

These provinces, based upon the geological and geographical distribution of the three native iron-ores employed, may be tabulated as follows:—

Provinces of iron-production.	Ores used.	Character of chief metals produced.	Seat of iron- or steel-making.
1. Frodingham...	Frodingham Ironstone (Lower Lias—calcareous and manganiferous), with addition of Northampton ironstone (Inferior Oolite—siliceous) drawn from an area extending from Mid Lincolnshire through Rutland into Northamptonshire.	Basic iron for making basic steel: Basic open-hearth steel.	Frodingham district (iron and steel).
2. Central	Marlstone Ironstone of Leicestershire and Mid Lincolnshire (Middle Lias—siliceous and calcareous), and Northampton ironstone of South Lincolnshire, Rutland and Northamptonshire (Inferior Oolite—siliceous) together.	Ordinarily, high-grade foundry- and forge-irons:	Leicestershire, Nottinghamshire and Derbyshire (iron).
	Northampton and Frodingham Ironstones together.	Now also basic iron for making basic steel.	——
3. Northamptonshire.	Northampton Ironstone of Northamptonshire and Rutland (Inferior Oolite—siliceous).	In ordinary times foundry- and forge- irons of several grades: now also in increasing amount basic iron for basic steel, by addition of manganese.	Northamptonshire (iron).

In some cases a small proportion of calcareous ironstone may replace limestone as a flux for insufficiently calcareous mixtures.

The above table does not account for the whole output of ore from these ironfields. A not inconsiderable proportion of the output of Northampton Ironstone from Northamptonshire and Rutland and of Frodingham Ironstone, as well as all the output of Marlstone ore from Oxfordshire, goes farther afield to other districts of iron-production beyond the influence of the local conditions of iron-making as determined by the distribution of these ironfields and the nature of their ores. Consequently, while the same mixtures are used for the same purposes in some Yorkshire furnaces, such part of the output may be employed for making other classes of iron and steel from different mixtures, and the Frodingham Ironstone may be used merely as ferric lime for fluxing insufficiently calcareous ores.

We are much indebted for information incorporated in this and succeeding chapters to the ironmasters and others interested in iron-production, and especially to Messrs. H. K. Scott and A. A. Dolan of the Ministry of Munitions, Messrs. J. Henderson and Julius Behrendt of the Frodingham Iron and Steel Co., Mr. A. Crooke of the Appleby Iron Co., the Redbourn Hill Iron and Coal Co., John Lysaght, Limited, Mr. James Fletcher of the Staveley Coal and Iron Co., Mr. Walter C. Fowler, late of the Stanton Ironworks Co., Messrs. T. Sarson and H. B. Hewlett of the Holwell Iron Co., Mr. Henry Preston, F.G.S., of Grantham, Mr. S. P. Lloyd, J.P., of Lloyd's Ironstone Co., Mr. N. J. Kidner of the Islip Iron Co., and Mr. W. Falcon of the Ebbw Vale Steel and Coal Co.

from Ores. Vol. XII, to Ores p. 71.

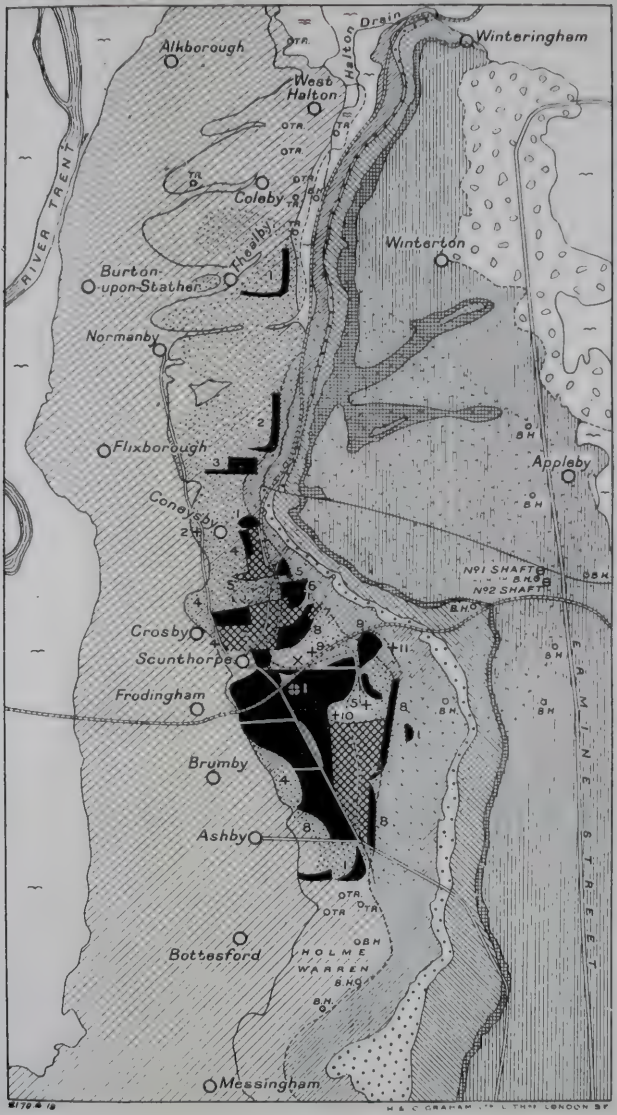

PLATE III. SKETCH-MAP OF THE FRODINGHAM ORE-FIELD NORTH LINCOLNSHIRE

INDEX

Alluvium & River Gravel

Drift

MIDDLE & LOWER OOLITES

Oxford Clay to Lincolnshire Limestone
Lower Estuarine Series and Northampton Sand.

LIAS

Upper & Middle

Pecten Bed
Clays above Frodingham Ironstone
Low^r Clays with Frodingham Ironst.
} Lower

Workable Frodingham Ironstone represented by close stipple at outcrop and by wider stipple under cover.

Ironstone worked out.

Upper part of Ironstone worked out.

\+ Ironworks
X. - disused.
B.H. Bore Hole TR. Trial Hole

IRONSTONE WORKINGS

1. Frodingham Iron & Steel C°
2. John Lysaght L^td
3. Yorkshire Iron C°
4. Midland Ironstone C°
5. Redbourn Hill Iron & Steel C°
6. Sheepbridge Iron & Steel C°
7. Walter Scott L^td
8. Lord St^r Oswald.
9. Trent Iron C°
10. North Lincolnshire Iron C°
11. Appleby Iron C°

SCALE OF MILES
0 1 2

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CHAPTER IV.

FRODINGHAM (LINCS.) DISTRICT (LOWER LIAS).

By C. B. Wedd.

Stratigraphy of the Ore-bed.

The Frodingham Ironstone occupies a position near the middle of the Lower Lias, which, as well as the Upper Lias, is much thinner in the neighbourhood of Frodingham and Scunthorpe than farther south. The following general section expresses the stratigraphical relationship of the Frodingham stone to other Jurassic ironstones of Lincolnshire[1]:—

	Ft.
Inferior Oolite:	
Lincolnshire Limestone	—
Shale (Lower Estuarine Series), at Appleby	33
Sandstone, representing *Northampton Ironstone* and Sand ...	2
Upper Lias:	
Grey Shale	26
Middle Lias:	
Marlstone Rock-bed (here a poor ironstone or locally merely a calcareous sandstone)	7 ft. — 8
Pale clays with cement-stone nodules, about...	70
Lower Lias:	
Pecten Ironstone (not worked), about...	4
Clays	90 ft.—95
Frodingham Ironstone, up to	32
Clay-shales, with thin-bedded limestones in lower part, estimated at	170

The Frodingham Ironstone roughly coincides in vertical range with the Ammonite-zone of Semicostatus, though where it is fully developed, the lowermost 4 or 5 feet should probably be assigned to the upper part of the underlying Bucklandi zone.

While more or less ferriferous oolitic limestone represents some part of this horizon from the Humber southward throughout and beyond Lincolnshire, the Frodingham bed as an ironstone workable under existing conditions has a narrowly restricted extent. From a point mid-way between the villages of Coleby and Thealby southward nearly to Bottesford (*see* map. Pl. III), a distance of about 7 miles, it is workable continuously along its outcrop; but northward and southward of these points it deteriorates rapidly as an ironstone, and, so far as is known, it nowhere recovers its quality.

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[1] *See* Rev. J. E. Cross, 'Geology of North-west Lincolnshire,' *Quart. Journ. Geol. Soc.* vol. xxxi, 1875, p. 115, and W. A. E. Ussher, 'Geology of North Lincolnshire' (*Mem. Geol. Surv.*), 1890. The Pecten Ironstone and some part of the overlying pale clays were regarded by H. B. Woodward as belonging rather to the Lower than to the Middle Lias [*see* 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iii, 1893, p. 243]; but in the absence of any line of division the whole thickness of these clays is here retained in the Middle Lias, as in the earlier classification. The thicknesses given are the approximate thicknesses in the neighbourhood of Frodingham and Scunthorpe.

The whole Semicostatus zone appears to be represented at Frodingham by about 27 feet of calcareous oolitic ironstone. But southward the lithological character of the strata changes, with a great increase of clay sediment, until 50 miles farther south, in North Leicestershire, near Barkston, Plungar and Harby this life-zone is represented by 150 feet of clays with a few limestone-bands and, at the base, a thin bed of more or less ferriferous oolitic limestone, which disappears southward[1] (cp. Pl. IV, Sect. 1 and Pl. VI, Sect. 2).

Northward a farther change of conditions is evidenced by a continued decrease of thickness, until the whole Lower Lias comprises only 150 feet or 100 feet of strata in South Yorkshire.[2]

As regards the extension of workable iron-ore under cover eastward, the existing evidence, derived mainly from a series of borings along the line of the Roman road in the neighbourhood of Appleby and for some distance southward, suggests that the ore keeps its thickness beyond the Roman road, opposite the central part of its outcrop (*see* map, Pl. III), but does not improve in quality.

In full thickness, as distinguished from thickness worked, the Frodingham Ironstone ranges from about 19 feet at the north and south ends of its working-area to a maximum of 32 feet in the middle in the neighbourhood of Crosby Warren, with an average of about 26 feet. It maintains a thickness of 29 feet or more for about 3 miles along its outcrop, from the latitude of Frodingham Station northward to Coneysby Bottom. But near Coleby, less than a mile beyond the most northerly workings, it diminishes to about 13 feet, besides deteriorating in quality; while southward from Ashby Ville at the south end of the working-area it varies rapidly and irregularly between full thicknesses of 5 feet and 19 feet (*see* Fig. 10).

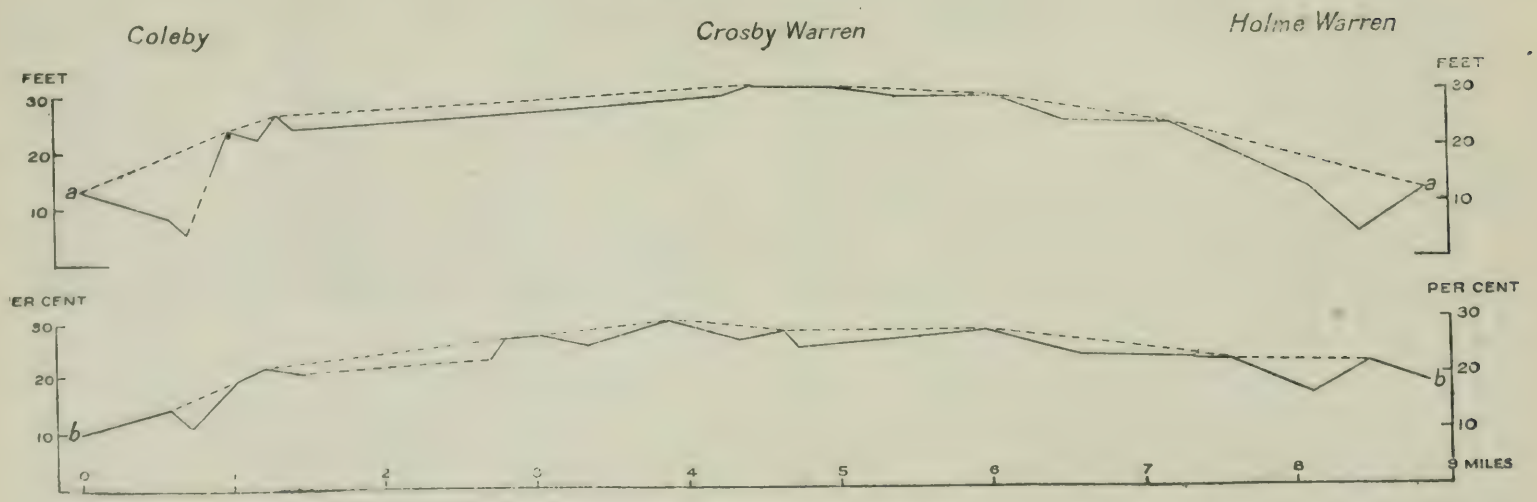
On the whole, the ironstone is best where it is thickest, the variations of iron-content rather closely following those of thickness as illustrated by the curves in Fig. 10. But this agreement does not hold good at the south end of the area, at Holme Warren, where, according to the evidence of one boring, a great part of the ore appears to have given place to shale, while the small remnant retains a fairly good quality. The average iron-content is 3 or 4 per cent. higher for a distance of about 3 miles in the middle than for the remainder of the worked outcrop.

In diminishing southward the ironstone seems to split into several beds, of which some die out, with an increase of intercalated shales. It is probably the lowest part that disappears first. Some part or parts persist for many miles farther; but the continuity of any one member with the band of ferriferous limestone at the base of the Semicostatus zone in North Leicestershire, should not be assumed.

The outcrop of productive ore, as defined above, has a width varying from $\frac{1}{2}$ mile to nearly 2 miles and embraces an area of nearly $8\frac{3}{4}$ square miles of stone that can be worked opencast. But

[1] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 24.
[2] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. i (Yorkshire), 1892, p. 68.

FIG. 10.—*Diagram to show the relationship between thickness and iron-percentage in the Frodingham Ironstone, along its outcrop from north to south.*



The upper curve shows the thickness; the lower curve shows the percentage of iron.
The continuous lines connect points at which the data have been ascertained.
The broken lines are generalised curves connecting the highest points.

owing to denudation of its slight westward rise, the actual thickness left diminishes westward. Moreover, the upper and less calcareous stone was worked off in former years over a not inconsiderable part of the outcrop. After making allowance for the rejection of a small proportion as unprofitable, the actual thickness worked averages 17 feet or 18 feet, and varies between a maximum of 30 feet 6 inches and a minimum of 2 feet at the extreme edge: but this minimum is only worked in conjunction with an available thickness of 6 feet or 8 feet in other parts of the same working. The dip may be regarded as roughly 1 in 100, or about half a degree, a few points south of east, in the northern part of the district; somewhat more in the central part, where the ironstone has protected the lower shales sufficiently to produce relatively high ground on the east bank of the Trent (*see* Pl. IV, Sect. 1), and the eastward dip is perceptible from a distance. But south of Scunthorpe the ground is flatter and the dip very slight.

The eastward dip is masked locally by scarcely perceptible undulations in a north and south direction, merely sufficient as a rule to determine a northward or a southward drainage in the workings. The ironstone, generally overlain at the surface by a varying thickness of blown sand, not shown on the map Pl. III, passes eastward under the higher shales or clays which come on gradually near the valleys of the Winterton and Bottesford Becks at the foot of the Oolite escarpment, and increase rapidly beyond as the ground rises to that escarpment; beyond the crest of which, in old shafts at Appleby, the thickness of cover amounts to 250 feet or more.

So far as the surface-working has yet extended eastward, the cover consists entirely of soft material. The blown-sand, irregular in distribution, locally absent, seldom many feet in thickness, and here and there including a bed of peat, constitutes the only cover in the western part of the working-area, and may continue eastward above an increasing thickness of Lower Lias clay. It is only at the eastern edge of the working-area, where the ironstone begins to pass under a rapidly increasing thickness of Liassic clay, that the cover is ever more than 12 or 15 feet thick. In one pit in such a position it has already reached a thickness of more than 60 feet; but in the present stage of working such a thickness is exceptional.

The working-area of the Frodingham Ironstone is remarkably free from faults. The only dislocation likely to prove of any practical consequence passes south of Appleby in a direction north of west towards Flixborough. It crosses the ironstone-outcrop at Coneysby Bottom, where the ore is not yet worked, and has disturbed the strata on the north side of the next working to the south.

Description of the Ore.

The unweathered Frodingham Ironstone consists essentially of a mass of aggregated beds of calcareous carbonate ironstone and more or less ferriferous limestone, both oolitic. But even at considerable depth the carbonate ore has always been partially

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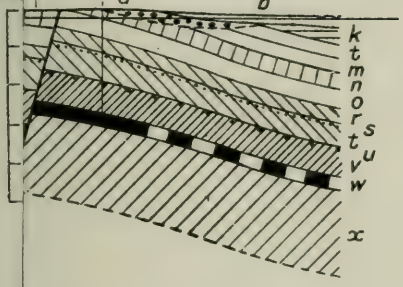


MID LINCOLNSHIRE.

Sixh

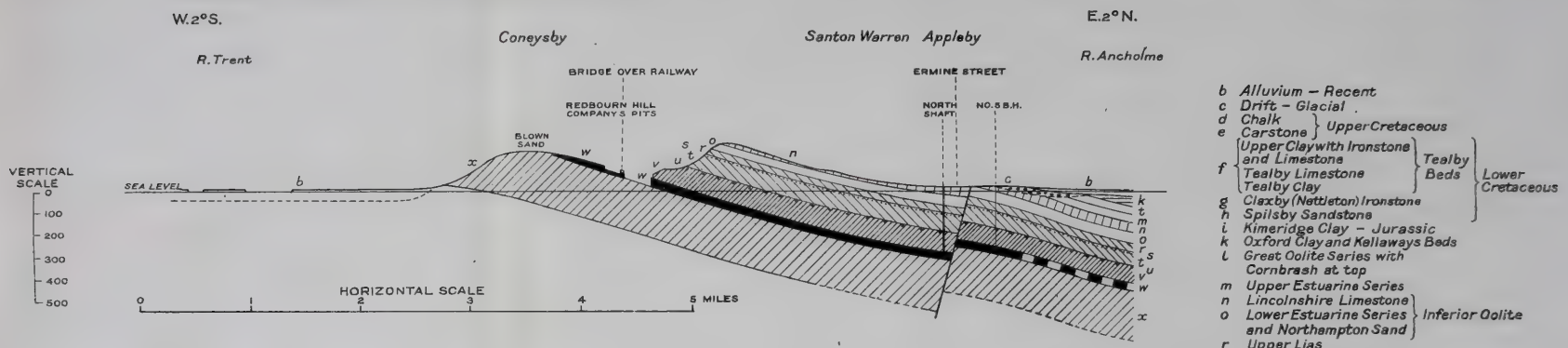
D

Rase

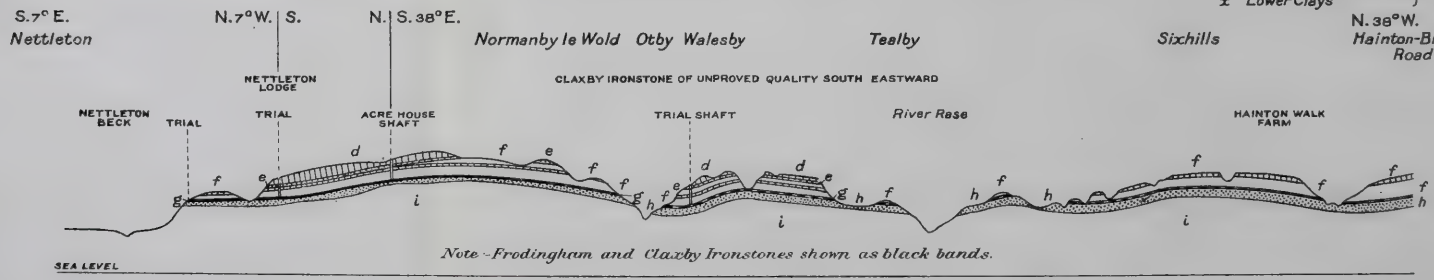
bands.

Iron Ores, Vol. XII. to face p. 74.

SECTION 1.–ACROSS THE FRODINGHAM ORE-FIELD, NORTH LINCOLNSHIRE, FROM WEST TO EAST.



SECTION 2.–ALONG THE COURSE OF THE CLAXBY IRONSTONE, FROM NEAR NETTLETON TO NEAR SIXHILLS, MID LINCOLNSHIRE.



Note – Frodingham and Claxby Ironstones shown as black bands.

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changed by oxidation. Individual beds seldom exceed 2 feet in thickness, and often vary greatly within a short distance. It is improbable that any single one could be traced far, though certain groups persist with the same lithological and palæontological features. Within the working-area the ironstone as a whole is remarkably free from argillaceous or arenaceous intercalations. A very few thin bands of dark shale or hard clay make their appearance here and there; but they seldom attain a greater individual thickness than 2 or 3 inches, though locally one of them may increase to nearly 1 foot. One such band strongly impregnated with iron pyrites and known as the 'sulphur band,' persists in the upper part of the ironstone for a mile or two in the south-eastern part of the district, and is usually rejected.

The ironstone varies, chiefly in iron- and lime-content, from bed to bed, and from place to place in the same bed. The difference between bed and bed is partly inherent, but is largely due to atmospheric agencies, and still more is the lateral change within individual beds. The variation in lime may range from *nil* to 30 per cent.; in metallic iron for the raw stone from 12 to 40 per cent. locally in weathered ore, though few beds contain less than 17 per cent. or more than 35 per cent. of iron.

Initial differences in the unweathered ore show a contrast between two extreme types, both characteristic of the Frodingham Ironstone, with various intermediate gradations. The two extreme types may be regarded as:—(*a*) a densely oolitic dark green calcareous carbonate ironstone consisting of closely aggregated green ooliths in a dark matrix, which looks almost black to the naked eye; (*b*) a less densely oolitic blue ferriferous limestone with grey ooliths in a bluish calcareous matrix, often containing streaks or bands of whitish crystalline calcite. The effect of prolonged water-percolation at and below the surface upon these culminates, at a late stage, in a soft decalcified ironstone, in which ooliths of a rich brown colour are closely packed in a soft brown matrix: finally, the top beds at the surface may disintegrate into an incoherent brown loam rich in ferric-oxide. Different degrees of weathering acting on the different initial types of stone produce the variations of lime-content, hardness and colour that are used by the iron-workers for a rough classification of the ore in working. The terms in general use are: "fine" or "mossy" (loam); "shingly" (weathered stone disintegrated into small subangular fragments); "soft" and "hard" "brown," "green," "blue," and "pink" stone, of which the latter four may be also "limy." These terms merely denote the local nature and condition of the stone, and have little stratigraphical significance But naturally the "fine" and "shingly" types are found only at the top. The harder and more calcareous types prevail in the middle and lower parts, while the "pink" stone is found generally at or near the bottom. Under the above reservations, the different types of ironstone alternate frequently near the surface, while even at a depth of 200 feet or more percolation and oxidation act selectively, and brown beds, though constituting a much less proportion of the whole, may be found under hard green or blue unweathered stone.

The above-described effects of weathering profoundly modify every bed of the ironstone as it rises in turn westward. Thus beds composed of hard limestone with a relatively low percentage of iron in the middle and lower parts of the ironstone are converted, by solution of calcium carbonate, oxidation of carbonate of iron, and removal of some insoluble matter, into soft brown, decalcified ironstone with a much higher percentage of iron.

The prevalent hue of the Frodingham Ironstone, as seen in the quarries or in heaps of mixed ore, is a dull deep reddish purple readily distinguishable from the reddish or yellowish brown of the weathered Marlstone and Northampton ores.

No definite lithological sequence can be determined within the Frodingham Ironstone, but a rough sub-division can be based on combined lithological and palæontological features. A group of beds in the middle of the ironstone is always highly calcareous in the unweathered state and always contains bands of a large *Cardinia*, so numerous that its thick calcite shells, commonly coated with green silicate of iron, add appreciably to the lime-content of the stone. These calcareous Cardinia-beds seem never to come in lower than about 5 feet above the base of the ironstone, and probably do not ascend higher than about 7 feet below the top, in the complete thickness of ironstone. The Cardinia-bands are not constant in number, and the group of beds that contains them varies from about 5 feet to about 16 feet in thickness. They form a conspicuous feature of the ironstone. In the thicker clay-phase of the Semicostatus-zone farther south *Cardinia* is not common.[1]

Another characteristic fossil is a *Gryphaea* of the group of *G. cymbium* Lam., usually rather small and thin-shelled. It occurs in large numbers in certain beds at intervals throughout the ironstone, but particularly in the lower beds. Numerous small-ribbed and smooth Pectens are found throughout; also a *Pholadomya*, locally abundant and near the top often retaining the position of life. Large specimens of *Plagiostoma* [*Lima*] *giganteum* (J. Sow.) occur occasionally in the lower beds.

The zone-ammonite *Arnioceras semicostatum* (Y. and B.) is fairly abundant in some parts, and appears to range from 4 feet or 5 feet above the base in the fullest development of the ironstone to the top. But large specimens of a *Coroniceras*, probably *C. gmuendense* (Oppel), prevail in the lowest 5 feet, though apparently not found higher; and on that account this lowest part of the ironstone should presumably be assigned to the Bucklandi-zone. *Oxynotoceras oxynotum* (Quenst.)—or allied forms—occurs in the clays above the ore and is said to have been found in the top bed of the ironstone.[2]

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[1] *See* "Geology of Melton Mowbray" (*Mem. Geol. Surv.*), 1909, pp. 32-3, and A. E. Trueman, "The Lias of South Lincolnshire," *Geol. Mag.*, Dec. vi, vol. v, 1918, p. 72.

[2] For lists of fossils of the Frodingham Ironstone, *see* Rev. J. E. Cross, "Geology of North-west Lincolnshire," *Quart. Journ. Geol. Soc.*, vol. xxxi, 1875, p. 122, and "Geology of North Lincolnshire" (*Mem. Geol. Surv.*), 1890, p. 22 and App. 1. These lists, however, need revision.

It was principally the calcareous Cardinia-beds that at an early stage of the development of the iron-field were necessarily rejected as mere limestone, to avoid excess of lime in the furnaces, when Frodingham ore was used by itself or with little admixture of siliceous ironstone.[1]

Chemical Composition.

While the chemical composition of individual beds varies widely, chiefly in the proportions of iron, lime, silica and alumina, the composition of the ironstone as a whole shows much less variation within the area in which the ore is worked. The Frodingham Ironstone is essentially a low-grade ore, with an average iron-content of rather less than 22 per cent. in the raw stone, before drying, and of about 25 per cent. in the same stone dried at 100° C. The iron is almost entirely in the state of ferric oxide (Fe_2O_3) in the brown weathered stone, and of carbonate ($FeCO_3$) with admixture of ferric oxide in the green unweathered stone.

The average percentage of silica and alumina is difficult to determine, owing to differences of method in presenting analytical results; but probably the total of these, "insoluble" and "soluble" together, averages about 14·5 per cent., there being a small excess of silica above the amount necessary for combination with alumina in silicates. The percentage of silica and alumina is certainly much greater in the upper and more weathered part than in the lower and more calcareous part of the stone.

The lime-content is the most variable. The average, for the whole thickness worked at several different workings, amounts to about 15·5 per cent., with extremes of about 9 and 21 per cent. But the variation in lime from bed to bed is greater, some beds in the weathered state being practically free from lime, while others, unweathered, occur as limestone with a low percentage of iron. It has already been mentioned that the middle and lower parts of the ironstone are in their ordinary state more calcareous than the upper, the difference resulting not entirely from weathering. Thus in one case, where a thickness of 30 feet 6 inches is worked, the upper 11 feet 8 inches averages only 4·15 per cent. of lime (the low percentage being largely the result of weathering), while the lower 18 feet 10 inches averages 18·14 per cent., and the whole 12·98 per cent. In another case, where the ironstone is worked under thick cover, including many feet of the overlying Lower Lias clays, and is less weathered than usual, the upper 12 feet 9 inches averages 15·84 per cent. of lime, the lower 11 feet 6 inches averages 25·21 per cent., and the whole (24 feet 3 inches) 20·2 per cent. But in a third case, where only the lower beds ranging up to 15 feet in thickness crop out near the western margin of the outcrop and are weathered, the average lime-content of these lower beds is only about 10 per cent.

A small amount of magnesia is generally present (1 or 1·5 per cent.), but is usually included with the lime in analyses.

[1] *See* G. Dove, "The Frodingham Ironfield, North Lincolnshire," *Journ. Iron and Steel Inst.*, 1876. pp. 320 and 327.

The average amount of manganese in the ironstone as a whole is fairly constant, never much less than 1 per cent., and seldom as much as 1·5 per cent. But, locally, the manganese is said to be concentrated in certain beds, which may contain individually as much as 33 per cent. of manganese peroxide[1], or nearly 21 per cent. of metallic manganese.

The sulphur-content is more variable, but always small. It probably averages about ·15 per cent. in the ironstone as used. But sulphur may be present in excess in occasional thin beds, which are rejected.

Phosphorus always occurs in small quantity, rarely less than ·15 per cent. or more than ·35 per cent. It is not always estimated in analyses, because it can be assumed not to be present in excess of the amount that can be dealt with by the smelting and refining processes employed. The average percentage of phosphorus may be taken as ·25. The phosphorus appears to be disseminated with the calcium carbonate, in the form of calcium phosphate.

The average amount of moisture contained in the raw stone in its natural state, as worked, may be taken to be 12·8 per cent., *i.e.*, the loss undergone by the stone when it is dried at 100° C. sufficiently to raise the iron-percentage from 21·8 to 25; but the actual amount varies according to the state of the weather.

In the following table the average values of the more important constituents of the Frodingham Ironstone are tabulated and compared with typical analyses of the workable ore in its normal and extreme aspects:—

Composition of Frodingham Ironstone.

Raw ore in moist state 'as received.'	Average values of the several chief chemical constituents of the Frodingham Ironstone. Percentages.	Typical analyses of workable Frodingham Ironstone, in normal and extreme aspects.		
		Normal ore (surface).	Richer ore (surface).	Poorer ore (underground).
Iron	21·8	21·95	26·83	19·89
Iron dried at 100° C	25·0	24·94	33·00	21·19
Silica	14·5	7·80	11·62	8·54
Alumina		4·49	4·14	(insol.)
Lime	15·5	18·12	9·06	20·29
Magnesia	1·3	1·05	1·23	—
Manganese	1·1	1·05	·987	1·19
Sulphur	·15	·04	·189	·664[2]
Phosphorus	·25	·31	·297	·318
Moisture...	12·8	11·90	18·70	9·55
Loss on calcination ...	—	22·70	16·91	—

[1] G. Dove, "The Frodingham Ironfield, North Lincolnshire," *Journ. Iron and Steel Inst.*, 1876, p. 320.

[2] Unduly increased by two beds, one of which would probably be rejected.

In comparison with other Jurassic ironstones the Frodingham stone is deficient in silica in relation to its lime-content, and contains enough lime to make a self-fluxing mixture with a certain proportion of Northampton or other siliceous ore. Its rather high percentage of manganese, besides reducing the small amount of sulphur present, admits of the admixture of siliceous ore without introducing silicon into the pig and rendering it unfit for steel-making by basic processes. The moderate phosphorus-content of the Frodingham ore makes this mixture suitable for the production of steel by the basic open-hearth process.

History and Development.

The Romans were evidently acquainted with the Frodingham ore as a source of iron, and worked the superficial weathered parts of it to a small extent, where not obscured by blown sand; for Roman pottery is found in association with old smelting-hearths, in which the slag, mixed with charcoal and rich in iron, remains undisturbed under a foot or two of soil.

There is no record or evidence of the ironstone industry at Frodingham and Scunthorpe since the Roman occupation until 1859, when Mr. R. Winn, the owner of all the property on which the ore was first worked, disposed of 2,000 tons of ironstone[1]. The amount increased to 16,000 tons in 1860[2]. In 1861 Messrs. W. H. and G. Dawes, of the Milton and Elsecar Ironworks, began the construction of a railway from the outcrop of the ironstone to the Trent for the purpose of shipping the ore; and erected furnaces at Frodingham in 1862[3], in which year the output of ore amounted to more than 50,000 tons[4]. From that date the Frodingham Ironstone has been worked continuously. The output increased steadily and exceeded half a million tons in 1875[5]. In 1876 the following ironworks were in operation[6]: —

Name of Company.	Furnaces.		
	In blast.	Out of blast.	Total.
Trent Iron Company	2	5	7
Frodingham Iron Company	2	2	4
North Lincolnshire Iron Company, Ltd. ..	2	2	4
Lincolnshire Smelting Company, Ltd. ...	1	1	2
Redbourn Hill Iron and Coal Company, Ltd	2	0	2
Appleby Iron Company, Ltd.	—	2 (building).	2
	9	12	21

In the early days of the Frodingham iron-industry, much of the ore raised was sent to Yorkshire, where it was probably mixed with other ores. But at Frodingham the local ore was at first used by itself without admixture of other ironstone. This required a careful selection of the beds to be used and involved a

[1] "Mineral Statistics of the United Kingdom" (*Mem. Geol. Surv.*).
[2] *Op. cit.*
[3] G. Dove, "The Frodingham Ironfield, North Lincolnshire," *Journ. Iron and Steel Inst.*, 1876, p. 320.
[4] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).
[5] *Op. cit.*
[6] G. Dove, *op. cit.*, p. 319.

classification of the whole into ironstones and limestones, the latter being, theoretically, rejected; but complaints arose, in the case of companies that did not themselves lease and work the ore they used, of the difficulty of buying it free from limestone. The ironstone beds selected, necessarily containing a greater percentage of iron than the whole thickness as now used, themselves carried enough lime for fluxing.[1]

A farther reason for excluding the more calcareous beds would lie in the amount of calcium phosphate associated with the calcium carbonate; for before the introduction of basic processes of steel-making, the phosphorus-content of the whole ironstone must have militated against the use for steel-production of any but the least calcareous parts of the ore.

The tracts worked up to and beyond 1876 lay entirely in the southern part of the district, and included at the surface the basal beds of the ironstone south of Frodingham Station, higher beds east of Scunthorpe village, and the upper beds more than a mile south-east of Frodingham. Consequently such parts as the highly calcareous Cardinia-beds (*see* p. 76), certainly rejected in their unweathered state, were included as good ironstone when weathered. For in many parts of the oldest workings the group of Cardinia-beds, more or less weathered, would be the only beds found near the surface.

A consequence of these earlier conditions of working was that only the surface-beds of the ironstone were worked, probably to no greater depth than 10 or 12 feet, and that, except on the western margin of the outcrop, where the basal beds come to the surface and are oxidized, all the lower part, to a thickness of 12 feet and more, was left in the ground, and is now being got, or remains to be got. The remaining area of this partially worked stone may be estimated at about one square mile.

The difficulty of selection led at one time to the addition of clay to the ore in the blast-furnace, to counteract the clogging effect of excessive lime. The clay, presumably Liassic, though its geological position is uncertain, was brought from Santon on the east side of Frodingham.[2] But before 1874 the present practice had been introduced of mixing siliceous Northampton Ironstone[3], then obtained exclusively from Lincoln and used in proportions varying from one-eighth to one-quarter[4].

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[1] G. Dove, 'The Frodingham Ironfield, North Lincolnshire,' *Journ. Iron and Steel Inst.*, 1876, pp. 320–1, and discussion, p. 333.

[2] G. Dove, *op. cit.*, p. 322, who records the composition of Santon clay as:—

	Per cent.
Silica	50·10
Alumina	22·72
Peroxide of iron	6·78
Lime	4·28
Magnesia	1·56
Water and organic matter ...	14·33
	99·77

[3] J. Dalgliesh and R. Howse, 'Some Remarks on the Beds of Ironstone occurring in Lincolnshire,' *Trans. N. of Eng. Inst. Min. and Mech. Eng.*, vol. xxiv, 1874-5, p. 25.

[4] G. Dove, *op. cit.*, p. 321.

Most of the workable area (*see* p. 72 and map, Pl. III.) of ironstone at or near the surface is owned by Sir Berkeley Sheffield, Bart., and Lord St. Oswald. Except that the latter owner himself raises a large amount of ore on his land and disposes of it to various iron-making firms at Frodingham or elsewhere, all this area is leased to eight companies, who work the ore chiefly for their own consumption, and smelt most of it at Frodingham.

In this way the whole surface-area, which may be farther defined as continuing eastward until the cover amounts to 100 feet, is divided into about 20 separate working-tracts, most of the companies holding leases in more than one part of the area. At least 18 of these separate tracts are now being worked, for the most part continuously, but in a few cases intermittently; so that practically every part of the surface area of workable ironstone is now being exploited.

Content, Output and Reserves of Ore.

The total area, nearly $8\frac{3}{4}$ square miles, as defined above, of ironstone at or near the surface, may be estimated to have contained altogether about 222,000,000 tons of ore, on the assumption that one acre one foot in thickness gives an average yield of 2,400 tons, and that the average thickness of workable stone is 24 feet in the eastern part (about $3\frac{3}{4}$ square miles) and 12 feet in the much denuded western part (nearly 5 square miles).

The following statistics of output of Frodingham Ironstone, in round numbers, for every fifth year from 1860 to 1880 inclusive, are derived from "Mineral Statistics of the United Kingdom" (*Mem. Geol. Surv.*):—

Year.	Output in tons.
1860	16,000
1865	125,000
1870	217,000
1875	417,000
1880	976,000

The total output from 1859 to 1881 inclusive was about 7,250,000 tons (*ibid.*). A calculation based on the later Home Office records gives about 52,500,000 tons as the total output of Frodingham Ironstone to the end of 1916, after deducting estimated quantities for the other iron-ores raised in Lincolnshire. The total returns of all iron-ores worked in the county amount to about 70,500,000 tons.

But the actual output of Frodingham iron-ore must fall short of the total diminution of ironstone-content of the whole ore-field during the same period. For, at any rate during the earlier half of the period, there was an appreciable wastage of ore in the rejection of calcareous beds that were then regarded as unfit for use (*see* pp. 79-80).

An independent calculation based upon the areas completely and partially worked out, and upon assumed average thicknesses, suggests about 69,000,000 tons as the amount by which the total content of the ironfield has been diminished during this period. Probably the actual total loss of iron-ore content down to the

end of 1916 has been about 60,000,000 tons. This would leave a reserve of 162,000,000 tons of ore under not more than 100 feet of cover; from which a further deduction of 2,699,532 tons must be made for the output in 1917[1], which shows a considerable increase due to the stimulus of war conditions.

At present all the ore is obtained by openwork, and the question of underground mining has scarcely yet been considered seriously. The underground extent of the Frodingham Ironstone as a workable ore is impossible to determine on the scanty existing data. But a few bore-holes and two shafts have been put down nearly on the line of the Roman road, Ermine Street, which runs northward through Appleby at a distance varying from $1\frac{1}{4}$ to $2\frac{3}{4}$ miles eastward of the surface-area of the ironstone. These trials extend from $\frac{1}{2}$ mile north of Appleby southward for about $2\frac{1}{2}$ miles (*see* map, Pl. III), and show no appreciable loss of thickness in the ironstone, but a slight diminution of iron-percentage as compared with the partially weathered and concentrated surface ore. If the north and south ends of this line of exploration be joined by straight lines to the corresponding ends of the surface-area as already defined, the included space will amount to about $9\frac{1}{4}$ square miles, which may be assumed to contain an average thickness of 26 feet of ironstone, or 374,000,000 tons of ore. This figure may be reduced to 336,000,000 tons to allow for a loss of 10 per cent. in pillars. While this is a minimum estimate as regards area (for south of Appleby the ore certainly extends a little farther eastward), the local inferiority of some beds, coupled with the difficulties of mining so great a thickness of ore, might greatly reduce the minable thickness and consequently the reserves actually available for mining.

Methods of Working.

A strong preference exists in the district for continuing the present system of open quarrying as long as possible before resorting to mining. One of the chief advantages of quarrying is that a large output can be obtained rapidly and cheaply; and the companies interested will probably prefer, in working eastward under increasing cover, to remove fully 100 feet of overburden sooner than resort to mining. Upwards of 60 feet is now being taken off in one case, and further improvements in machinery are expected to enable still greater thicknesses to be removed economically. The cover, where at all thick, is always stripped off by steam-navvy; but thin cover is usually removed by hand.

Much of the ironstone is still being worked by hand; and in some quarries hard beds require blasting, notably a hard, grey, calcareous bed near the top in the central part of the area; but the use of steam-diggers is increasing. Certain advantages are lost by the change of method, for where the working-face of ironstone can be graded into several 'lifts' of different character, these lifts are loaded separately by hand-labour, and this facilitates accurate mixing for the furnace. But the steam-digger

[1] F. H. Hatch, 'Average Analyses of British Iron-ores and Ironstones produced in 1917-18.' (*Ministry of Munitions of War.*)

necessarily mixes the stone indiscriminately by digging a great thickness together, for the whole thickness is then divided into not more than two or three lifts.

Whereas formerly the more calcareous parts of the ore-bed were rejected, and much of the lower part was left in the ground, under present conditions the admixture of siliceous ore to counteract the excess of lime and the introduction of basic processes, which permit the use of phosphoric ores for steel-making, have made it possible not only to utilize the whole thickness of the Frodingham Ironstone in the blast-furnaces, but even to re-work ground from which the less calcareous upper ore had been worked off. In fact, these lower beds can be used apart from the upper, by mixing with them a greater proportion of Northampton Ironstone. The only parts of the ore-bed now rejected are such as may contain too little iron for profitable use in the furnace—theoretically, any part containing less than 17 per cent. of iron—and an occasional clay-band, if either its thickness or its sulphur-content justifies the trouble of elimination by hand-picking.

The working of the ore eastward below the level of the streams has resulted in some inconvenience in the matter of drainage. Several companies have combined in a joint system of pumping to free their workings from water and at the same time to supply their engines. For this purpose the water so obtained from the ironstone is not good, and other supplies have been secured recently.

The Great Central Railway Company have, on their line from Grimsby to Doncaster, extensive mineral-sidings at Frodingham, from which standard-gauge branch-lines, some privately owned, run to the ironstone-workings on both sides. Besides these, a light railway from Scunthorpe northward by Trealby serves the more distant workings on that side. These railway facilities, though considerable, are generally felt in the district to be inadequate to present needs.

As the different leases are often parallel strips of ground, the mineral-lines cross and serve the leases of several companies. The line of intersection of these leases, being thus fixed, determines the plan of working. Successive working-faces, starting from the fixed point at which the line enters or leaves a lease, may radiate fan-wise on either side, to get as long a 'face' as possible without any abrupt bend.

At the present time six companies have blast-furnaces in the district, five of them near the Great Central main line, the sixth some distance farther north. Two of these companies are also making steel on the spot, while one or two others were, in 1917, about to begin steel-production there. Four companies lease and work their own ore at Frodingham, but the other two buy all the Frodingham ore they use. Four other iron or steel companies quarry this ore for their own use in Yorkshire and Derbyshire: and some of the ore is also sold for smelting in the Manchester and Sheffield districts, at Middlesbrough, and in Derbyshire. When used at a distance from its source, the Frodingham Ironstone in some cases becomes a secondary constituent of the ore-mixture, and is regarded as 'ferric lime' added to flux the mixture and at the same time to increase its iron-content.

Most of the companies making iron at Frodingham, either calcine or roast the ore-mixture before putting it into the blast-furnace. The difference between the two processes may be stated thus: that in calcinating, the ore is subjected to the flame of burning gases; in roasting, only to the heat of burnt gases, without coming into contact with the flame. Both processes are carried out in kilns of various types. Two methods of calcining are in use: (*a*) ore and coal in alternate layers are ignited by burning gas from the blast-furnace; (*b*) burning gas is passed over the ore without admixture of coal.

No reserve of quarried Frodingham ore is kept as a rule, the ore going direct from the quarries to the kilns or the blast-furnaces. Consequently, as the rate of quarrying, as well as the condition of the stone, varies with the weather, the composition and condition of the mixture may vary to some extent, and as the result of unfavourable weather an excessive amount of slag may be produced in the blast-furnace.

At first, calcining was done in open heaps or 'clamps,' as it still is in the case of the much less calcareous Northampton Ironstone. But it was found that this method of calcining rendered the highly calcareous Frodingham ore too friable on exposure to the weather.[1]

For the blast-furnace a considerable proportion of Northampton Ironstone, always a siliceous ore, is mixed with the Frodingham stone, to supply more silica for combustion with the excess of lime in the Frodingham ore, and so to save fuel and accelerate the working of the furnace. Moreover, the Northampton ore, being richer in iron, increases the iron-content in the furnace, without increasing the sulphur or notably increasing the phosphorus; while the Frodingham ore supplies enough manganese to prevent excess either of sulphur or of silicon in the pig for basic steel-making. The proportion of Northampton ore used may vary with circumstances and requirements; but, naturally, more of it is added in the mixture now than formerly, when only the less calcareous parts of the Frodingham ore-bed were utilized. The mixture of Frodingham and Northampton ore is, of course, self-fluxing.

Northampton Ironstone is obtained largely from Lincoln, but also from Leadenham and districts farther south in Lincolnshire, from Rutland, and even from more distant parts of Northamptonshire.

Hitherto, practically no other ore has been employed for the blast-furnace mixture at Frodingham.[2] The Cretaceous Claxby Ironstone of North Lincolnshire is considered quite suitable as a siliceous constituent, but until the present time it has been rejected, chiefly on the score of expense of working and transport. Now, however, one company has made arrangements to mine it for that purpose.

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[1] G. Dove, 'The Frodingham Ironfield, North Lincolnshire,' *Journ. Iron and Steel Inst.*, 1876, p. 323.

[2] In one case, however, a small proportion of siliceous Marlstone ore from South Northamptonshire is used, perhaps without realization that it is not "Northampton Ironstone" in the geological sense.

Local Details, Analysis, etc.

The map, Plate III., indicates in a general way the surface of workable ironstone as divided between the several companies that lease or own the ore. The Frodingham Iron and Steel Company have eight working-areas, comprising the north and south ends and some of the central parts of the ironstone-outcrop. Three of these form a continuous tract around the Company's works east of Frodingham Station and are now nearly exhausted; while the Ashby Ville lease, at the south end, has been abandoned as unremunerative. The Company nowadays obtain their supply of Frodingham ore from their Thealby, Coneysby, Crosby Warren and Yarborough pits, besides buying ore from Lord St. Oswald; but in 1917 work had been suspended temporarily at Crosby Warren, and the bulk of the ore then being used was coming from the Thealby and Yarborough pits.

The Frodingham Company work the ore partly by hand, in which case the whole thickness is divided into several 'lifts,' loaded separately, and partly by steam-digger, with a tendency to increase the proportion of work done by mechanical means. Thick cover, as in the Yarborough lease, is removed by special cover-digger with long-arm transporter.

The company sell only a small amount of their ore; they use in their own blast-furnaces nearly all their output, mixed with a certain proportion of Northampton Ironstone and roasted in kilns, for making chiefly basic iron for steel-production.

Messrs. John Lysaght, Ltd., having works situated between Scunthorpe and Flixborough, nearly two miles north-west of Frodingham Station, hold a large lease skirting Normanby Park in the northern part of the area, and a small detached tract a little farther south.

They work their ore now entirely by steam-digger. None of it is sold. They use their Frodingham ore in the raw state, with the addition of Northampton Ironstone from Lincoln and elsewhere, in their blast-furnaces, which produce basic iron for steel-production.

The Yorkshire Iron Co., Ltd., have a single area adjoining the south side of Messrs. Lysaght's lease, but have no furnaces in the district. They use their Frodingham ore in their own furnaces. The Redbourn Hill Iron and Coal Co., Ltd., besides holding a tract not yet worked at Coneysby Bottom on the south side of the Yorkshire Iron Co.'s lease, have their principal holding of ironstone in the central part of the outcrop, and their ironworks, near which they have worked out a considerable area of ironstone, a mile east-south-east of Frodingham Station. Until recently this company have worked the ironstone entirely by hand, in several lifts, loaded separately. But they are now using the steam-navvy, which works the ore in two lifts. They calcine their Frodingham ore in kilns, with addition of Northampton ore, which they buy.

The Midland Iron Company, Ltd., owned jointly by the Staveley and Parkgate Companies, work four separate areas of ironstone in the Frodingham district, viz., Berkeley lease, south of the Frodingham Iron and Steel Company's Coneysby lease; Crosby and Glebe leases, respectively north and south-east of Crosby village, both small areas on the outer margin of the outcrop; and Beauchamp lease on the south-west margin. They get the ironstone chiefly by steam digger, but also partly by hand. Both methods are used in their Berkeley lease; the Crosby lease is worked entirely by hand; and the other two entirely by mechanical means.

The Sheepbridge Coal and Iron Company, Ltd., have a lease in the middle of the outcrop between the Redbourn Hill Company's working-area on the north and the Frodingham Company's Crosby Warren lease on the south. They work the ore by hand except the lowermost seven feet, which will be got by steam-digger.

Messrs. Walter Scott, Ltd., who have their furnaces at Leeds, lease the next area southward. They remove thick cover by steam-digger, but work the ore by hand.

Lord St. Oswald works his own ironstone in several separate workings, viz.:—Crosby pit (between the workings of Messrs. Walter Scott on the north and the Trent Company on the south); a long continuous tract extending southward from the Trent Company's ground to the southern limit of workable stone, and divided into three workings known as 'No. 4,' 'No. 3,' and 'Wing,' in order from north to south; Chatterton pit, on the south-west margin, between the Midland

Company's Beauchamp lease and the Frodingham Company's Ashby Ville lease. He works the ironstone partly by hand, partly by steam-digger, but is extending his use of the latter method of working.

The Trent Iron Company, Ltd., hold a lease extending chiefly along the north side of the Great Central Railway, but passing also to the south side, their furnaces being situated on the north side. They work the ironstone chiefly by hand, the hard lower beds being blasted and the larger lumps broken by hand; but in 1917 they had installed one steam-digger. They use their ironstone in the raw state in their own furnaces, with the addition of Northampton ore from Lincoln, for the production of basic pig for steel-making.

The Appleby Iron Company, Ltd., have no surface-area of Frodingham Ironstone, but retain a lease of ground for future mining between Appleby Station and Appleby village. They buy all the Frodingham ore used in their furnaces, chiefly from Lord St. Oswald, and calcine it for smelting with the addition of Northampton ore.

The North Lincolnshire Iron Company, Ltd., with furnaces less than a mile east-south-east of Frodingham Station, work no Frodingham ore themselves, but buy from Lord St. Oswald. They calcine the ore, with admixture of their own Northampton Ironstone from Easton, near Stamford.

A series of borings on the outcrop north of the working-area from a point about three-quarters of a mile north of West Halton village southward beyond Coleby to a point half a mile north of the most northerly working at Thealby, proved the ironstone-bed for a distance of more than a mile and a half, and showed a variable iron-content ranging from only 6·8 per cent. to 15·7 per cent. in the moist stone, for a full thickness of 13 ft. or less. Only one of these trials (in Coleby village) showed any ironstone of workable quality, viz., 3 ft. 7 ins. of good ironstone with an average iron-content of 24·5 per cent. (moist stone) in a total thickness of 10 ft. 10 in., mostly very poor stone, for the iron-percentage of the whole thickness amounted to only 15·7. Consequently, though few of these borings passed through the full thickness of the undenuded bed, the ironstone has evidently diminished considerably in thickness and deteriorated greatly in quality, in the short distance northward from the nearest working.[1]

Thealby Pit (*Frodingham Iron and Steel Co.*).—This, the most northerly of the ironstone-pits, is one of that Company's more recent working-areas, and only a small proportion of the ground has been worked out. Cover is thin or absent. The maximum thickness of ironstone, so far as the working has extended eastward, is about 18 ft. 6 in., the top beds having been removed by denudation. The whole remaining thickness is worked. The complete thickness of the bed, where it passes eastward under the Liassic clays in the immediate neighbourhood, ranges from 23 ft. to 27 ft., as proved by boring.[2]

The following average analysis represents the composition of the ironstone in the Thealby Pits in Sep ember, 1918:—

Raw ore.	As received. Per cent.	Dried at 100° C. Per cent.
Iron	22·90	25·90
Silica	[7·10][3]	8·00
Alumina	[3·90]	4·40
Lime	[20·40]	23·00
Magnesia ...	[·76]	·86
Manganese ...	[1·08]	1·22
Sulphur	[·09]	·11
Phosphorus ...	[·32]	·36
Moisture	11·30	—

The next lease southward (John Lysaght, Ltd.), adjoining the Frodingham Iron and Steel Company's Thealby lease, has been worked only for a few years and merely a narrow strip along the east side has been exhausted. The cover, consisting of blown sand, ranges in thickness from 3 ft. to 8 ft. 6 in., and the

[1] Based on information supplied by the Frodingham Iron and Steel Co., Ltd.

[2] Information from the Redbourn Hill Coal and Iron Co., Ltd.

[3] Here, and elsewhere throughout, matter within square brackets is additional to the original account.

ironstone, which, as there worked, includes all but the highest part of the ore-bed, from 5 ft. 6 in., where most denuded, to 17 ft. 3 in., with an average of about 13 ft. The average composition of the ironstone worked in July, 1916[1], was:—

Raw ore, as received.

	Per cent.
Iron	21·10
Silica	8·25
Alumina ...	5·42
Lime	18·63
Magnesia ...	1·12
Manganese ...	1·10
Sulphur ...	·045
Phosphorus ...	·31
Nickel ...	·009
Chrome ...	·005
Oxygen ...	9·70
Loss	20·99
Moisture ...	12·92

Total insoluble	9·54
Fe in perfectly calcined stone	31·93

In the adjoining area on the south (Yorkshire Iron Co., Ltd.) the cover of blown sand ranges in thickness from nil to several feet; but the ground containing the thickest cover and the greatest thickness of ore at the east end of the area has not yet been worked.

The following is a partial analysis of the Yorkshire Company's Frodingham Ironstone:—[2]

Raw ore, as received.

	Per cent.
Iron	21·28
Iron (dried ore)	24·40
Silica	5·76
Lime	19·34
Moisture	12·80

The next lease southward (Redbourn Hill Coal and Iron Co.) includes the shallow depression known as Coneysby Bottom. In 1917 it had not begun to be worked, but trialing is stated to have proved the ore to be satisfactory. However, an apparent line of disturbance traversing the depression in a westerly direction (*see* p. 74) and the possibility of erosion beneath the blown sand, may cause trouble in some parts of this area.

The Coneysby lease (Frodingham Iron and Steel Co.), a relatively small area projecting into the south-eastern part of the tract last described, shows on its north side, where it approaches the above line of disturbance, a strong northward dip accompanied by some disruption and confusion of the ironstone-bed. This part of the working had been temporarily abandoned in 1917. Only a small part in the south-east corner of the lease has been worked out. The cover is blown sand of no great thickness and the ironstone is similar to that of neighbouring workings.

In the Berkeley pit (Midland Iron Company, Ltd.), the next to the south, most of the working has been done on the west side of the road from Scunthorpe to Winterton. A considerable part in the middle of this lease, amounting however to less than half, has been worked. The thickness of ironstone in this worked area is about 22 ft. for the north-western quarter, where alone the whole thickness has been got, but increases to 30 ft. southward within the lease. In the remaining three quarters of the worked area the lower part to a thickness of about 10 ft. has been left in for the present, while the upper two-thirds, amounting to 20 ft. in the southern part, has been worked off, in two 'lifts,' by steam-digger.

[1] From a detailed analysis supplied by John Lysaght, Ltd.

[2] From F. H. Hatch, 'Average analyses of British Iron-ores and Ironstones produced in 1917-18' (*Ministry Munitions of War*), 1918.

A fault crosses the east side of the worked area at about 45 yds. south of the north boundary of the lease, where it has a northward downthrow of about 8 ft. It runs south of west and crosses the west side of the pit about 90 yards south of the north boundary, with much-diminished throw.

The cover, chiefly of blown sand, ranges from one or two feet to somewhere about 12 ft. locally.

In a small triangular corner of the lease east of the railway and the road, the ironstone passes under the overlying Lower Lias clay, which, so far as the work has proceeded, is only a few feet in thickness, but is increasing. This part is worked by hand.

The following analyses[1] show the composition of different types of the Frodingham Ironstone in the Berkeley pit, and of a mixture of these, probably, however, excluding the lower beds:—

Raw ore, as received.	Fine. [Weathered and disintegrated loamy ore at top.] 1.	Shingle. [Weathered and broken ore near top.] 2.	Rough. [Solid, partially weathered ore.] 3.	Rough. [Solid, partially weathered ore.] 4.	Mixed. 5.
Iron	27·53	29·13	24·78	27·74	26·83
Iron (dried at 100° C.)	35·80	38·00	27·90	32·50	33·00
Silica	20·22[2]	14·03	5·86	6·82	11·62
Alumina	5·19	5·12	3·23	3·35	4·14
Lime	1·19	2·11	17·89	17·20	9·06
Magnesia	·90	·939	1·40	1·47	1·23
Manganese ...	1·16	1·58	1·35	1·345	·987
Sulphur	·058	·090	·496	·507	·189
Phosphorus ...	·210	·418	·298	·264	·297
Moisture	23·12	23·35	11·17	14·65	18·70
Loss on calcination	12·76	13·26	23·10	20·99	16·91

From hereabouts for three miles south-eastward the ironstone everywhere maintains a full thickness of not less than 29 ft. and is at its best.

Of the next area southward, the Sheffield lease (Redbourn Hill Co.), a considerable part has been fully worked out, on both sides of the railway, which traverses this and succeeding areas on the south. In earlier years the lower 12 ft. was not worked, but since the whole thickness came into use, these lower beds have been completely worked out to the limit of eastward working on the east side of the railway. Of the full thickness of the ironstone, amounting to 30 ft. 6 in. in the eastern 'face,' the upper three beds, viz., the much weathered and disintegrated 'fine' and 'shingly,' and the 'mossy brown' beds, are richest in iron. But the last-named, together with a 'hard grey limestone' below, thins out westward and becomes unrecognizable. This hard limestone is the only bed here that requires blasting. The 'sulphur-band' (a thin bed of hard pyritous clay-stone) is present only in the east 'face,' and was there picked out by hand. Apart from this thin band, the whole thickness of the ironstone has there been used. The composition is shown in the tables of analyses which follow.[3]

[1] From the Midland Iron Co.

[2] This is obviously due in part to blown sand derived from the cover.

[3] From the Redbourn Hill Coal and Iron Co., Ltd.

Analyses of Ironstone of the Redbourn Hill Co.'s Sheffield Workings.

1. Face east of Winterton Road, 50 yds. south of Pump at north end.

Raw ore, as received.	Chingley. [Shingly.]	Mossy brown.	Tea-leaf.	Soft brown limestone.	Soft yellow and brown.	Soft green.	Pink & grey limestone.	Blue limestone.	Average of section.
Thickness ...	2′ 6″	2′ 6″	4′ 0″	2′ 8″	6′ 9″	2′ 7″	4′ 0″	5′ 6″	30′ 6″ total.
	1.	2.	3.	4.	5.	6.	7.	8.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	30·26	32·07	27·18	28·37	28·81	25·84	15·51	20·16	25·78
Iron (dried at 160° C.)	39·40	44·30	32·20	34·00	34·00	29·40	17·00	22·70	30·37
Insoluble	12·67	6·08	21·27	5·84	4·49	6·42	3·67	5·86	7·91
Alumina	5·53	6·01	5·91	6·50	4·83	5·90	3·86	4·71	5·21
Lime	1·61	1·16	2·95	10·84	12·72	12·85	25·74	21·76	12·98
Sulphur	—	—	—	·18	·39	·08	·17	·15	·16
Moisture	23·20	27·60	15·60	16·60	15·20	12·00	8·20	11·20	15·12

2. Face east of Winterton Road. at middle.

Raw ore, as received.	Fine.	Chingley. [Shingly.]	Thin brown limy.	Tea-leaf.	Soft blue and brown.	Soft blue.	Pink and blue shelly.	Blue shelly.	Average of section.
Thickness ...	1′ 7″	1′ 8″	2′ 9″	2′ 0″	5′ 0″	3′ 0″	9′ 3″	4′ 6″	29′ 9″ total.
	1.	2.	3.	4.	5.	6.	7.	8.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	23·11	27·82	17·48	18·67	24·19	28·59	18·72	18·00	21·23
Iron (dried at 100° C.)	27·00	31·80	18·70	20·70	27·30	32·20	20·50	19·70	23·53
Insoluble	27·39	18·64	9·16	27·99	9·74	6·83	5·45	5·66	10·10
Alumina	5·56	6·21	4·95	6·68	6·20	5·40	4·84	3·65	5·10
Lime	4·28	4·81	24·50	9·93	14·62	11·54	24·19	25·59	15·67
Sulphur	—	—	·15	·15	·32	·76	·30	·11	·26
Moisture	14·40	12·50	6·50	9·70	11·40	11·20	8·70	8·60	9·77

3. Face west of Winterton Road, 150 yds. from Bridge.

Raw ore, as received.	Fine brown.	Tea-leaf.	Soft brown and black.	Soft brown and blue.	Blue limy.	Blue shelly.	Average of section.
Thickness	1′ 11″ 1.	3′ 0″ 2.	2′ 3″ 3.	5′ 11″ 4.	4′ 2″ 5.	6′ 2″ 6.	23′ 5″ total.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	18·90	22·34	23·48	30·79	20·54	20·00	22·62
Iron (dried at 100° C.)	22·00	26·50	28·50	37·10	23·00	22·70	26·37
Insoluble	7·64	21·08	13·18	4·31	2·94	3·52	7·13
Alumina	4·23	6·67	5·18	5·12	3·55	3·93	4·65
Lime	22·07	7·92	9·06	9·46	23·21	22·46	16·15
Sulphur	—	—	·19	·36	·18	·08	·16
Moisture	14·10	15·70	17·60	17·00	10·70	11·90	14·18

In the next lease southward (Sheepbridge Coal and Iron Co., Ltd.) the middle part has been worked out except the lowest 7 ft. The ironstone here reaches its maximum thickness of 32 ft., no part of which is rejected except the top of the fine weathered surface-ore. The cover attains a thickness of 16 ft. in the north-east corner of the working face, where it consists of 10 ft. of blown sand overlying 6 ft. of Lias clay.

The following is an analysis[1] of the Sheepbridge Company's Frodingham ore :—

Raw ore, as received—	per cent.		per cent.		per cent.
Iron	24·45	Lime	16·75	Phosphorus ...	·28
Iron (dried at 100° C.)	28·43	Manganese ...	·95	Moisture	14·00
Silica	7·62				

At the west end of this tract the small Crosby lease (Midland Iron Co.) occupies the extreme outer edge of the ironstone-outcrop and is the most westerly area actually worked. Only the bottom beds, here well weathered and of an average thickness of 9 ft., are present. Work has only recently begun on this lease. There is little cover.

South of the Sheepbridge lease, the Crosby Warren pit (Frodingham Iron and Steel Co.) has been worked extensively. From the western part the surface-beds of the ore have been worked off in former years, and in more recent years the middle part has been worked out completely. But more than one-third at the east end remains intact. The thickness of ironstone increases from about 22 ft. in the middle to about 30 ft. at the east end. The cover consists of about 6 ft. of blown sand in the middle of the lease, but increases eastward where the ore passes under Lias clay.

The following partial analyses[2] give the principal constituents of the successive types of ore constituting the whole ironstone at Crosby Warren :—

[1] From F. H. Hatch, 'Average Analyses of British Iron-ores and Ironstones' (*Ministry of Munitions of War*), 1918.

[2] From the Frodingham Iron and Steel Co., Ltd.

CROSBY WARREN PIT (OLD FACE: 450 YDS FROM EAST END).

December 18th, 1912.

Raw ore.	Thickness.	As received.		Dried at 100° C.			
		Moisture.	Iron.	Insoluble.	Iron.	Lime.	Sulphur.
	Ft. In.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
Baring	6 0	—	—	—	—	—	—
Sandy fine	1 5	25·5	23·6	34·2	31·8	1·6	·030
Brown fine and shingly	1 0	15·4	26·8	21·1	31·6	6·8	·020
,, ,, ...	1 4	14·7	24·2	32·6	28·3	4·4	·016
Brown rough and shingly	1 9	17·8	24·4	16·5	29·8	11·6	·076
Green and brown	1 8	14·2	24·4	18·9	28·0	10·8	·034
Brown and limy	1 0	13·9	25·0	5·1	29·0	18·2	·040
Soft brown	0 8	15·8	38·1	5·9	45·2	4·6	·030
Green shelly	0 10	10·9	22·4	5·7	25·1	21·4	·296
Green	1 6	16·5	34·2	6·1	41·0	6·8	·118
Green and limy	2 0	14·7	34·9	4·5	40·9	6·4	·716
,, ...	1 10	9·4	25·6	6·3	28·3	16·2	·104
,, ...	2 6	11·0	18·7	3·9	21·0	28·0	·612
,, ...	2 10	11·5	18·0	5·5	20·4	23·6	·114
Pink and shelly	1 7	9·6	15·9	2·5	17·6	30·4	·118
[Total	21 11 (ironstone)	13·9	24·5	11·2	28·6	14·3	·139]
		Averages.					

Immediately west of the Crosby Warren lease a small area extending to Crosby village has been completely worked out and abandoned. South of this, the Glebe lease (Midland Iron Co.) constitutes a small tract on the margin of the ironstone-outcrop, immediately north of Scunthorpe village. Here the surface-beds of the ore were worked off in former years and the Midland Iron Co. have recently begun to work the lower beds, averaging 8 ft. 3 in. in thickness. These, since they do not form the natural surface of the ground, are here little weathered and highly calcareous.

On the south side of the Crosby Warren lease, in the area leased by Walter Scott, Ltd. (Leeds Steel Works), the western part—more than half—has been worked over once, and the lower beds are now being got out. The upper beds also are being worked in the eastern part.

The following vertical section, which may be regarded as typical of the district, gives the sequence and approximate thicknesses of the constituent beds of the ironstone exposed in the south 'face,' about 30 yards from the east end:—

	Thickness. Ft.	in.
Blown sand ... ... 8 ft. to	10	0
Light grey shaly clay, up to	20	0
Calcareous ironstone, about	0	10
Rather hard brown ironstone	1	2
Shale parting (irregular)	0	1
Grey calcareous ironstone, with *Gryphaea cymbium* ...	0	5
Hard, rather calcareous light brown and grey ironstone with *Gryphaea* and *Belemnites*	1	2
Grey and brown ironstone with *Gryphaea cymbium* and *Pholadomya*	1	2
Dirt and shale parting	0	3
Hard brown ironstone with *Gryphaea* and *Pholadomya* ...	0	8
Shale parting, impersistent, up to	0	1
Brown ironstone	0	5
Hard, fine dark grey and brown ironstone	0	5
Softer grey and brown ironstone	1	2
Dark greyish-brown ironstone with calcareous bands ...	1	4
Softer dark grey and brown ironstone: some *Cardinia* ...	0	5
Rather soft dark brown ironstone with *Gryphaea cymbium*	1	1
Harder calcareous dark grey and brown ironstone with beds of large *Cardinia*	3	2
Rather massive brown ironstone, rather calcareous, with *Gryphaea cymbium*	2	8
Dark brown stone with green calcareous bands	1	2
Brown and green calcareous stone with large *Cardinia* ...	0	9
Thickness of ironstone-bed in section ...	18	5

The section gives the whole thickness of ironstone worked in this "face," but a farther thickness of 13 ft. lies below the floor. Appearances suggest, however, that only the upper 3 or 4 ft. of the lower stone is worth working in this part of the lease, the rest being too calcareous for use under existing conditions, though the corresponding beds are being worked in the western part of the Company's holding.

While the cover amounts to 30 ft. at the eastern limit of working, in the greater part of the area it consists merely of waste material from the earlier working.

The following is an analysis[1] of this Company's Frodingham ore:—

	Raw ore, as received. Per cent.
Iron	23·12
Iron (dried at 100° C.)	24·83
Silica	6·80
Alumina	4·70
Lime	21·91
Manganese	·87
Sulphur	·36
Phosphorus	·27
Moisture	6·90

[1] From F. H. Hatch, 'Average Analyses of British Iron-ores and Ironstones (*Ministry of Munitions of War*), 1918.

In the next area southward, the Crosby Pit (Lord St. Oswald), about one quarter at the west end has been worked over, and roughly half of this has been worked out completely, the cover there being merely a few feet of blown sand.

The following measured section, at the south-west end of the present working-face, gives the divisions recognized in working the ore and the percentages of iron and moisture in the several beds[1] :—

——	Thickness.	Moisture.	Iron in moist stone.	Iron in stone dried at 100° C.
	Ft. in.	per cent.	per cent.	per cent.
Top pink	1 7	4·9	31·95	33·60
Flaky pink	1 5	4·8	31·31	33·00
Rough pink	1 11	4·3	27·94	29·20
Snap	1 6	4·0	21·12	22·00
Pink	1 7	3·9	24·50	25·50
Blue	1 11	4·7	28·59	30·00
Shelly blue limy ...	3 2	4·4	27·91	29·20
Limy blue	1 11	3·0	22·31	23·00
Blue limy	1 9	3·3	24·46	25·30
Blue limy	2 10	3·1	22·57	23·30
Shelly blue	1 10	3·2	19·06	19·70
'Colly' rock	2 11	4·3	21·95	22·90
Total ...	24 4	4·08	25·33	26·43
			[Average.]	

The Trent Iron Co. hold a lease extending mainly along the north side of the Great Central Railway, but including ground on the south side of it, north and east of the Frodingham Iron and Steel Co.'s works.

The only part of this area yet worked is the eastern part south of the railway. The thickness of ironstone got varies from about 17 ft. to 22 ft., but in this tract, enclosed by higher ground on all sides and already excavated considerably below the level of the Bottesford Brook, 5 or 6 ft. of good stone at the bottom is being left in for the present, partly owing to the difficulty of dealing with water, and one of the lower Cardinia-beds forms the floor of the pit. Moreover, in the north-east part of the east 'face' the highest beds are locally poor in iron and are rejected.

The cover, nowhere thick, consists of two beds of blown sand separated by peat, which here and there contains tree-trunks.

The following sections and partial analyses show the character of the ironstone[2] :—

East Face (length 680 yds.).

1. 40 yds from N.E. end—

——	Thickness.	Raw ore, as received.			
		Moisture.	Iron.	Insoluble.	Lime.
	Ft. in.	per cent.	per cent.	per cent.	per cent.
Rejected	7 3	—	—	—	—
Flaky fine	2 11	15·6	24·1	22·3	4·4
Flaky brown ...	1 3	15·4	23·1	19·9	7·1
Green pyrites ...	0 8	14·4	19·1	6·8	27·0
Good brown	1 6	18·7	31·2	4·7	9·4
Good blue	3 4	11·4	27·6	4·9	13·8
Hard blue	2 4	12·7	25·3	4·1	17·5
Shelly blue	1 11	9·0	25·3	4·1	17·5
Limy blue	2 3	10·0	20·9	4·9	23·0
Black	1 7	11·7	19·6	5·5	23·3
Thickness { Rejected	7 3	—	—	—	—
Thickness { Stone ...	17 9	13·0	24·58	8·79	14·46
	25 0				
			[Average.]		

[1] From Lord St. Oswald.

[2] From the Trent Iron Co.

2. 200 yds. from N.E. end—

——	Thickness.	Raw ore, as received.			
		Moisture.	Iron.	Insoluble.	Lime.
	Ft. in.	per cent.	per cent.	per cent.	per cent.
Rejected	0 6	—	—	—	—
Fine	5 0	15·3	24·7	18·5	5·1
Flaky brown ...	2 11	13·0	25·7	13·8	10·1
Good brown	1 10	15·7	28·8	5·8	12·5
Limy brown ...	1 1	10·0	23·7	4·5	27·0
Good blue	2 2	10·6	30·1	5·1	13·2
Good blue and brown	2 10	10·5	29·0	5·7	2·8
Hard blue	1 4	8·4	20·3	4·8	24·4
Shelly blue	0 10	4·7	22·1	6·1	20·9
Limy blue	3 4	1·0	17·2	4·0	32·7
Black	0 4	9·3	18·9	5·6	24·8
Thickness { Rejected	0 6	—	—	—	—
Thickness { Stone ...	21 8	10·53	24·62	9·33	15·65
	22 2	[Average.]			

West Face (length 240 yds.).

3. 200 yds. from N. end—

——	Thickness.	Moisture.	Iron.	Insoluble.	Lime.
	Ft. in.				
Flaky and fine ...	—	3·8	31·0	8·4	11·0
Limy brown ...	—	2·8	21·8	3·9	26·6
Limestone	—	1·7	17·7	2·4	31·2
Limy brown ...	—	3·5	23·2	5·0	22·5
Hard blue	—	4·0	20·2	5 1	23·0
Pink limestone ...	—	3·6	17·6	3·3	27·9
Black	—	16·8	23·1	6·6	17·9
		3·9	24·2	5·86	19·93
		[Average.]			

4. North end—

Fine	1 8	10·6	26·6	27·7	1·9
Flaky	2 1	9·3	30·9	11·1	8·1
Limy flaky	1 0	11·6	23·1	5·1	20·1
Brown	6 0	11·7	34·3	5·3	8·5
Blue	2 9	7·0	24·5	10·0	26·0
Blue limestone ...	1 6	4·8	19·8	5·5	27·5
Limy brown ...	1 2	5·7	20·0	4·7	26·4
Pink limestone ...	2 1	7·9	19·3	5·5	23·0
Limy blue	1 3	8·1	24·5	4·4	18·7
Limestone	1 1	6·4	16·6	2·8	29·8
Total ...	20 7	9·01	26·56	8·13	12·90
		[Average.]			
Average of nine sections		12·24	24·75	8·67	14·53

The following is a fuller representative analysis[1] :—

Trent Iron Co.

Raw ore, as received—	Per cent.
Iron	23·20
Iron (dried at 100° C.)	27·29
Silica	5·60
Alumina	2·10
Lime	20·70
Magnesia	1·20
Manganese	1·16
Sulphur	·12
Phosphorus	·35
Moisture	15·00

The Trent Company's furnaces are situated upon their lease north of the railway. The Frodingham Iron and Steel Co. hold an extensive area extending southward from the Trent Company's lease. The north-western part of this is occupied by their works and furnaces. Most of this area has been worked out, but a small remnant, south-east of the works, was still being worked in 1917.

East of this, the North Lincolnshire Iron Co.'s furnaces are situated.

Immediately to the eastward the Redbourn Hill Iron and Coal Co. hold an area on which their works stand, and in which they have worked out a considerable amount of ironstone.

Eastward and southward from the Trent Co.'s and the Redbourn Hill Co.'s leases, Lord St. Oswald works a large area. Except along the east side of this, most of the ground has been worked over once and the upper beds of ironstone removed. But along the east side, in the series of working-faces extending from the Trent Company's ground southward for almost two miles, nearly the whole thickness of the ironstone-bed is being worked. The amount of lower beds there left in may be 7 ft. in the northern part, but is less farther south. These workings are divided into sections named, in order from north to south, 'No. 4 Face,' 'No. 3 Face,' and 'Wing Face.' In them the cover varies from about 5 ft. to probably 30 ft. The middle of 'No. 3' traverses a shallow synclinal depression, trending eastward, in which pale blue shaly clay (Lower Lias) overlying the ironstone attains a thickness of 10 ft. or more. This is planed off horizontally above, so that there is a much greater thickness of clay in the syncline than elsewhere, and dies out southward along the present line of working. The rest of the cover consists, where thick, of blown sand, in places gravelly at the bottom, with one or two thin films of mud or clay and in the upper part a peat-bed (continuous with that of the Trent workings) three or four feet thick.

The following section gives lithological details, with iron-workers' terms in brackets, of the ironstone-bed in No. 3 Face at a point 1¾ m. E. 43° S. from Frodingham Station, at the "Old Pump" :—

	Ft.	in.
Weathered and disintegrated fine-grained brown loamy ironstone ('Fine')	0	9
Hard brown thin-bedded calcareous ironstone consisting of brown ferruginous ooliths not very densely aggregated in a calcareous matrix, with patches of crystalline carbonate of lime and shells (*Gryphæa cymbium*) ('Flaky Lime')	0	10
Soft weathered and decalcified ironstone, with ooliths not very densely aggregated: some calcareous shells ('Soft Brown')...	1	8
Similar ironstone, some *Gryphæa cymbium* in upper part ('Soft Brown')	0	10
Hard brown and greenish-grey calcareous ironstone with brown weathered ooliths variably distributed in a matrix partly brown and decalcified, partly greenish-grey crystalline calcite: abundant small *Gryphæa cymbium* in upper part ('Hard-brown Limy')	0	6

[1] From F. H. Hatch, 'Average Analyses of British Iron-ores and Ironstones produced in 1917-18' (*Ministry of Munitions of War*), 1918.

	Ft.	in.
Hard brown and greenish-grey rather densely oolitic calcareous ironstone, with shell-fragments (' Blue and Brown ')... ...	0	7
Weathered brownish-grey ironstone with brown ooliths in a marly-looking matrix, partly brown and partly grey: some *Gryphaea cymbium* (' Soft Dark Grey')	1	2
Partially weathered brown and green calcareous ironstone, with brown ooliths rather densely aggregated in a matrix partly brown and oxidized, partly green and calcareous: some shells (' Soft Blue and Brown ')	1	0
Green and brown speckled ironstone, with brown ooliths variably aggregated in a matrix for the most part green and of marly appearance (' Blue and Brown Speckled ')	2	0
Similar ironstone with brown ooliths more densely aggregated: some *Gryphaea* (' Blue and Brown Speckled ')	1	5
Similar ironstone: some *Cardinia* and *Gryphaea*	0	10
Similar ironstone, but more calcareous and shelly: abundant *Cardinia*, some *Gryphaea* (' Light Blue Speckled Shelly ') ...	1	2
Soft brown weathered densely oolitic ironstone (' Soft Brown ') ...	0	4
Harder green and brown streaky ironstone with brown ooliths, rather densely aggregated in a calcareous matrix with shelly bands (*Cardinia ?*) (' Blue and Brown Limy ')	0	8
Hard dense dark grey muddy-looking limestone perhaps containing carbonate of iron, 1 in. to 3 in.: average	0	2
Brown and greenish-grey streaky, shelly and calcareous ironstone with brown ooliths not very densely aggregated in a matrix partly brown and decalcified, partly greenish-grey and calcareous (' Blue and Brown Limy ')	0	3
Similar ironstone, but less shelly (' Brown and Blue Limy ') ...	0	3
Brown and greenish-grey ironstone with polished brown ooliths variably aggregated in a light greenish-grey calcareous matrix (' Blue and Brown Limy ')	0	6
Similar ironstone, with ooliths in brown parts more densely aggregated: *Gryphaea* (' Blue and Brown Limy ')	1	2
Green and brown speckled ironstone, with brown ooliths rather densely aggregated in a dark green matrix apparently consisting largely of carbonate of iron: small smooth *Pecten* and other shells (' Blue and Brown ')	1	3
Dark green and brown speckled ironstone, with dark brown polished ooliths variably aggregated in a dark greenish-grey matrix apparently consisting largely of carbonate of iron: some calcareous shells, including *Gryphaea cymbium ?* (' Blue and Brown Speckled ')	1	1
Dark grey muddy limestone	0	1
Brown and green streaky calcareous oolitic ironstone with *Cardinia* (' Brown and Blue Streaky ')	0	5
Total	18	11

The bottom of the ironstone was not reached, there being probably at least 5 ft. more below the floor.

The individual beds of the ironstone vary greatly in detail. The ' Sulphur-band ' usually present in the upper part of the ironstone of this neighbourhood was not recognized in the above section; for comparison with which another section of the upper beds about 200 yrds. farther north, in the trough of the syncline, is appended, in which the abundance of *Pholadomya* makes a farther noticeable difference:—

	Ft.	in.
Light bluish-grey and pinkish-purple clay, shaly in upper part, and calcareous below: small *Gryphaea cymbium* and *Pholadomya*, both abundant	1	0

	Ft.	in.
Bluish-grey, rather soft oolitic ironstone, somewhat clayey: ooliths unevenly distributed in clusters: *Pholadomya* abundant, many at the top of the bed being in the position of life: some *Gryphaea cymbium*	0	10
Dark brown densely oolitic ironstone with some green streaks: *Pholadomya* abundant, especially in lower part	2	0
Hard pink and green oolitic somewhat calcareous ironstone, with bed of *Gryphaea cymbium*	1	0
Dark greenish-grey highly pyritous clay-stone: small cavities have a scoriaceous appearance: some small *Gryphaea* (the 'Sulphur-band') ... ... 6 in. to	1	0
Light brown speckly densely oolitic, more or less calcareous iron-stone: ooliths brown, often with soft and ochreous cores, in a green matrix: abundant large *Gryphaea*-shells make the stone calcareous: thickness variable ... ... about	0	2
Soft bluish-green muddy-looking more or less calcareous ironstone, with brown ooliths	0	10
Dark blue calcareous shaly clay, with unevenly scattered brown ooliths: *Pholadomya* and a small smooth *Pecten* ... 3 in. to	0	4
Soft green and brown, brown-speckled densely oolitic ironstone: ooliths ochreous inside, about	0	8
Harder light-brown streaky oolitic ironstone, with calcareous bands: some *Gryphaea*	0	10
	8	8

The following sections and partial analyses[1] illustrate the sequence and quality of the ironstone at intervals along the line of the above three working faces:

1. No. 4 Face, near Santon Cottages.

	Thickness. Ft.	In.	Moisture. per cent.	Raw ore. Iron in moist stone.	Iron in dried stone.
Pink	1	2	8·3	26·22	28·60
Pink	1	0	8·2	29·10	31·70
Snap	2	3	7·5	22·66	24·50
Pink	1	5	10·8	23·90	26·80
Blue and Brown	1	10	11·6	26·69	30·20
Shelly Blue	1	4	9·9	27·48	30·50
Blue and shelly Blue ...	2	0	11·0	29·63	33·30
Blue	3	0	12·1	30·94	35·20
Blue Limy	2	6	11·8	30·69	34·30
Shelly Blue Limy	1	8	7·1	22·29	24·00
Blue and Pink Limy ...	2	4	9·4	21·10	23·30
Shelly Blue	1	5	9·5	24·88	27·50
Total	21	11	Av. 10·02	26·52	29·47

2. No. 3 Face, 52 chains S. of Goose-hole, and 25 yds. from Old Pump.

Brown Flaky	2	3	10·4	21·14	23·60
Shingly	1	8	10·7	27·05	30·30
Shelly Brown and Blue ...	1	3	9·3	17·59	19·40
Pink	2	4	7·2	19·48	21·00
Hard Blue	2	1	6·5	21·13	22·60
Blue Limy	1	10	5·8	22·32	23·70
Blue Limy	1	6	6·7	24·35	26·10
Limy Blue	1	9	5·0	21·85	23·00
Blue Limy	3	7	6·1	23·47	25·00
Pink Limy	1	11	7·6	24·94	27·00
Total	20	2	Av. 7·39	22·41	24·19

[1] From Lord St. Oswald.

3. Wing Face at South end.	Thickness. Ft.	Ins.	Moisture. per cent.	Raw Ore. Iron in moist stone.	Iron in dried stone.
Pink	2	2	7·5	26·08	28·20
Pink Limy	1	7	6·8	21·43	23·00
Brown Limy	1	8	4·9	20·73	21·80
Clayey Blue	0	9	5·7	13·01	13·80
Snap	2	3	6·0	13·16	14·00
Hard Limy Pink	1	2	4·8	21·51	22·60
Blue and Brown	1	11	8·4	27·75	30·30
Blue	2	4	5·6	24·26	25·70
Snap	1	2	4·3	18·66	19·50
Snap	2	6	4·1	17·45	18·20
Black	1	11	7·5	26·45	28·60
Black Limy	1	3	5·2	21·61	22·80
Total	20	8	Av. 5·99	20·92	22·55

The Yarborough lease (Frodingham Iron and Steel Co.) extends along the east side of the above ground. Work on it has only recently begun. Here the thickness of cover removed is greater than anywhere else in the district, and amounts to 60 ft. or a little more, consisting of about 30 ft. of Liassic clay underlying sand, with peat.

The following details[1] show the character and composition of the ironstone as worked :—

Yarborough Pit, 20 yards from tunnel at north end.

Raw ore.	Thickness. Ft.	Ins.	As received. Moisture.	As received. Iron.	Dried at 100° C. Iron.	Dried at 100° C. Insoluble.	Dried at 100° C. Lime.	Dried at 100° C. Sulphur.
Blue and Brown	1	4	11·1	28·4	31·9	21·1	6·2	·068
Pink and Brown	1	3	11·5	26·4	29·8	18·7	11·1	·058
Blue and Brown	1	3	11·8	23·3	26·4	25·8	10·8	·112
Blue and Brown Limy ...	1	1	11·6	14·9	16·9	16·1	24·7	1·770
Blue and Green Limy ...	1	3	11·0	18·2	20·5	26·9	12·7	·504
Blue and Brown Limy ...	1	6	12·7	23·5	26·9	10·0	19·6	·232
Brown Limy	1	3	11·6	23·0	26·1	5·3	24·0	·214
,, ...	1	3	9·7	20·2	22·3	4·9	28·8	·082
Brown and Green Limy	1	4	14·1	34·1	39·8	6·7	9·5	·274
,, ,, ,,	1	3	16·7	30·0	36·0	6·1	12·0	·150
,, ,, ,,	1	4	10·6	25·5	28·6	3·7	22·9	·160
Brown	1	0	17·1	35·4	42·7	6·8	7·0	·620
Brown and Blue Limy	1	3	8·4	19·4	21·2	3·9	29·6	·608
Green and Brown Limy	1	6	10·5	16·4	18·3	3·9	32·6	·142
Green Limy	1	0	9·7	21·6	24·0	4·4	26·8	·164
Soft Blue	0	6	14·3	27·4	32·0	11·3	12·7	·054
Green and Limy ...	1	0	13·1	18·3	21·1	8·1	26·3	·170
Brown and Green Limy	1	1	9·2	15·3	16·9	4·1	32·8	·054
Brown and Blue Limy	1	0	12·4	23·2	26·5	7·4	21·0	·050
,, ,, ,,	0	7	12·1	20·3	23·1	9·4	22·0	·060
Pink and Green Limy ...	1	3	9·2	16·9	18·6	3·3	31·1	·524
Total	24	3	Av.11·	22·87	26·11	9·5	20·2	·288

On the west side of the outcrop, the ground north and south of Frodingham and Scunthorpe Station has long been worked out. South of this, by far the greater part of the Beauchamp lease (Midland Iron Co.) has also been worked out, and in all this area it is believed that nowhere more than 3 ft. of the basal stone was left in the ground. Only the marginal south-western part remains unworked, and the stone there is now being got. The length of the working-face is nearly three-quarters of a mile. Only the lower beds of the ironstone are present; and in one

[1] From the Frodingham Iron and Steel Co., Ltd.

part a slight anticlinal roll brings the base of the stone to the surface for a short distance. The thickness of ironstone varies from a workable minimum of 2 ft. to a maximum of 15ft. 3 ins., with an average of 10ft. 3 ins. The cover is nowhere more than a few feet of sand.

This working affords a good illustration of the weathering and decalcification of the more calcareous lower beds at the surface. Several of these at the top of the section are seen to oscillate between the conditions of a hard green or blue ferriferous limestone, and a thoroughly decalcified soft brown ironstone. The following is an average analysis[1] of the ore:—

Raw ore, as received.	per cent.
Iron	24·61
Iron (dried at 100° C.)	36·40
Silica	12·95
Alumina	4·37
Lime	10·04
Magnesia	1·23
Manganese	·815
Sulphur	·158
Phosphorus	·240
Moisture	19·02
Loss on calcination	17·41

Ammonites of the Semicostatus zone are abundant, except in the lowest four or five feet, in which large specimens of *Coroniceras gmuendense* are found.

In the next area southward, the Chatterton pit (Lord St. Oswald), about half the productive ground has already been worked out. The following sections and partial analyses[2] show the character of the beds:—

Chatterton Pit.

1. Section at North-west end of working-face.

Character of Ironstone.	Thickness. Ft. Ins.	Moisture. per cent.	Raw Ore. Iron in moist stone.	Iron in dried stone.
Flaky Fine	1 11	10·8	26·31	29·50
Flaky Lime	2 4	6·1	18·31	19·50
Brown and Yellow	0 11	11·2	27·52	31·00
Siliceous Brown	2 2	10·7	27·95	31·30
Lime	0 5	4·1	14·57	15·20
Pink Limy	1 10	4·9	19·12	20·00
Pink	1 0	5·3	23·39	24·70
[Total	10 7	Av. 7·96	22·43	24·37]

2. Section at South-east end of working-face.

Flaky Fine	1 5	14·1	27·74	32·30
Flaky Lime	2 3	10·2	18·40	20·50
Siliceous Brown	1 7	12·4	25·22	28·80
Siliceous Brown	1 11	11·8	25·04	28·40
Brown Limy and Soft Brown	0 8	8·2	23·40	25·50
[Total	7 10	Av. 11·57	23·50	26·57]

These beds represent only the middle and lower parts of the ironstone, which is thinning southward. But as the amount of ore below the 'siliceous' beds of the more northerly section, which are regarded as containing more siliceous matter than the generality of the constituent beds of the Frodingham Ironstone, is considerably greater than the amount below the corresponding beds in the southern section, it seems likely that the lowest beds have there disappeared southward or have passed into shales.

Of the Ashby Ville lease (Frodingham Iron and Steel Co.) at the extreme south end of the worked area, a comparatively small part was worked out, before this tract was abandoned. Probably the complete local thickness of the Ironstone-bed is present in the south-eastern part of the ground worked; but the whole ironstone has diminished in thickness and several beds of clay have made their appearance within it. The thickness of ore found ranges from 4 ft. 5 in. to 7 ft. 8 ins. in the

[1] From Mr. J. Fletcher. [2] From Lord St. Oswald.

south-eastern part of the ground, where the complete thickness of the bed, so far as it can be defined, with included clay, amounts to 9 ft. 6 in. The amount of cover varies from about 2 ft. of soil to 12 ft. 6 in. of sand, with peat.

The following sections and partial analyses[1] illustrate the character of the ironstone :—

West end of working, near Grange Farm—

	Thickness. Ft.	Ins.	Ore as received. Iron.	Dried at 100° C. Iron.	In-soluble.	Lime.
Sand	4	0	—	—	—	—
Sandy Fine [Ironstone] ...	0	4	11·8	15·2	63·5	2·0
Fine Pine	0	5	18·3	24·4	43·4	2·2
Fine Clayey	0	4	15·1	20·5	46·6	1·2
Pink Fine and Shingly ...	0	6	20·6	26·2	21·6	13·4
Brown Fine and Shingly	0	10	14·6	16·8	22·1	23·2
Pink Shingly	0	9	20·6	25·0	18·2	17·0
Brown Fine and Shingly	0	11	15·8	20·0	14·6	20·4
Pink Shingly	0	6	20·8	23·9	15·6	19·4
[Total Ironstone ...	4	7	Av. 17·32]			

Middle of working, 340 yards from West end—

	Thickness. Ft.	Ins.	Ore as received. Iron.	Dried at 100° C. Iron.	In-soluble.	Lime.
Soil	2	6	—	—	—	—
Brown Fine	0	11	16·1	20·6	31·0	6·6
Clay	1	1	13·8	17·7	43·9	12·4
Pink Fine and Shingly ...	0	11	22·6	27·5	23·2	9·2
Clay	0	6	18·5	23·4	36·0	7·0
Pink Shingly	0	9	19·3	21·9	13·1	22·2
Brown Fine and Shingly	0	7	17·4	20·2	26·9	15·6
Pink Shingly	0	10	18·7	22·6	25·2	16·4
Brown and Limy ...	0	9	20·6	24·4	7·9	23·8
Brown Shingly ... nil to	0	9	23·4	28·3	13·4	15·8
Pink Rough and Shingly nil to	1	0	20·8	23·9	17·6	19·4
[Total Ironstone ...	6	6	Av. 19·01]			

Near east end, 150 yards from Bridge—

	Ft.	Ins.	Ore as received. Moisture. %	Iron. %	Dried at 100° C. Iron. %	In-soluble.	Lime.	Sulphur.
Baring	12	6	—	—	—	—	—	—
Brown Fine and Shingly Limy	0	6	10·0	17·4	19·3	9·8	28·9	·046
Clay	1	10	—	—	—	—	—	—
Brown and Blue	0	9	8·5	16·8	18·4	15·0	25·9	·052
Brown Fine and Shingly	1	0	13·2	19·6	22·6	24·1	14·6	·134
Brown and Blue Limy ...	1	0	6·6	24·1	25·8	8·3	17·6	1·220
Brown Shingle	0	8	11·4	28·6	32·3	6·6	13·4	·134
Brown Shingle, Limy ...	1	1	5·7	20·5	21·7	3·6	28·0	·110
Blue and Brown, Limy ...	1	2	4·9	26·4	27·8	14·2	15·1	·140
Limy Rock ...	0	6	5·4	15·6	16·5	10·2	30·9	·252
Soft Blue and Brown ...	0	7	9·7	19·4	21·5	25·7	11·1	·434
Blue Rock, Limy	0	5	6·7	12·1	13·0	9·3	32·8	·131
[Total Ironstone	7	8	Average	21·23]				

[1] From the Frodingham Iron and Steel Co., Ltd.

The rapid change that takes place southward, shows south of Ashby Ville both a diminution of total thickness of ironstone-beds and a general deterioration of quality, though at first a few beds, aggregating 5 or 6 feet of ironstone, show little or no diminution of iron-content. The following three sections,[1] at intervals of about half a mile, illustrate the change. All apparently include the top of the ironstone-bed, and at least one of them the complete thickness of it:—

No. 1 Borehole, 1·15 m. E. 7° S. from Bottesford Church.

	Ft.	Ins.	
Baring	20	0	
Brown [Ironstone]	0	4	
Brown and Blue Limy	1	0	
Bluish Brown	1	0	
Blue, Rough and Shingly	1	6	
Shelly	0	6	
Brown	0	4	
Limy	0	11	
Black	1	6	
Pinkish	2	0	
Limy	1	10	
Brown	0	10	
Limy	1	6	
			[Ironstone, 13 ft. 3 ins.]
Blue Clay	1	6	
Limy [Ironstone]	0	5	
Blue Clay	2	4	
Clay and Limy [Ironstone]	2	3	
Clay	2	0	
Clay and Limy [Ironstone]	1	9	
Clay	2	6	
Limy [Ironstone]	1	4	
			[Total Ironstone-bed 27 ft. 4 ins.]
Clay	2	8	

No. 2 Borehole, 1·3 m. E. 27° S. from Bottesford Church.

	Ft.	Ins.	
Sand, 15 ft. 0ins. / Clay 12ft. 5ins. } Baring ...	27	5	
Brownish Clayey [Ironstone] ...	1	1	
Brown	1	7	
Brown	1	2	
Brown	1	3	
			[Ironstone, 5 ft. 1 in.]
Clay	6	2	
Limy Clay	2	0	
Limy [Ironstone] and Clay	3	5	
			[Ironstone-bed, 16 ft. 8 ins.]

No. 3 Borehole, 1·2 m., S. 43° E. from Bottesford Church.

	Thickness. Ft.	Ins.	
Sand, 20 ft. 0in. / Clay, 7ft. 3ins. } Baring	27	3	
Limy [mere limestone]	1	3	
Blue [ironstone]	0	9	
Brown	1	0	
Dark Brown	0	9	
Clay [ferriferous]	2	8	
Limy [ironstone]	1	9	
Clayey Brown	1	7	
Shelly Brown	1	6	
Bluish	1	6	
			[Ironstone, 9 ft. 7 ins. Total Ironstone-bed, 12 ft. 3 ins.]

[1] From the Frodingham Iron and Steel Co., Ltd.

The average iron-content of the beds regarded as ironstone in these three sections is as follows[1] :—

	Total Ironstone-bed.	Ironstone.	Iron (as received).	Iron (dried).
No. 1 ...	27 ft. 4 ins.	13ft. 3ins.	15·87 per cent.	17·12 per cent.
No. 2 ...	16ft. 8 ins.	5ft. 1in.	20·54 per cent.	22·36 per cent.
No. 3 ...	12 ft. 3 ins.	9ft. 7ins.	16·46 per cent.	18·09 per cent.

The foregoing sections suggest that it is chiefly the lower beds that change first in passing southward, with diminution of iron-content and development of clay; and that in the Ashby Ville workings, except at their east end, only the lower beds are present, there less changed than further south.

On the Appleby Iron Company's lease two shafts[2] were sunk many years ago about a mile south of Appleby village. Only the more northerly of these, half a mile north-west of Appleby Station, reached the top of the Frodingham Ironstone, at a depth 293 ft.

A boring[3] made many years ago at Spring Wood Lodge, 2¾ miles south of Appleby, proved the Frodingham Ironstone to be 24 ft. 3 ins. thick at a depth of 258 ft. 6 ins. Another[4] 1 mile and 2 or 3 chains due west of the Spring Wood Lodge borehole found 30 ft. of ironstone at a depth of 81 feet.

Six borings have been carried out by the Appleby Co. for the purpose of testing the ironstone under thick cover. Four of these are situated near and west of the Roman road Ermine Street and range from about half a mile north of Appleby village to nearly two miles south of it (*see* map, Pl. III.), a fifth, half a mile east of the southern shaft, and a sixth nearly a mile west of Appleby Station. A re-examination of the cores of No. 1 Borehole, the most southerly, was made by permission of the Appleby Iron Co. and the Frodingham Iron and Steel Co. The following section is based on this examination and, in the case of soft strata, for which complete cores have not been preserved, upon the borer's record :—

No. 1 Appleby Borehole.

	Thickness. Ft. Ins.	Depth. Ft. Ins.
Recent—		
Sand	16 0	16 0
Lincolnshire Limestone—		
Limestone, red (oolitic)	19 5	35 5
Limestone hard compact	7 2	42 7
Limestone, clayey	8 11	51 6
Clay	4 10	56 4
Limestone, hard compact	11 2	67 6
Clayey limestone	5 4	72 10
Lower Estuarine Series—		
Clay	17 6	90 4
Northampton Sand—		
Sandstone	1 6	91 10
Upper Lias—		
Clay, dark, in part shaly, with two 7-inch bands of limestone in lower part	59 6	151 4
Middle Lias (*Marlstone*)—		
Sandstone, pale greenish-grey, more or less calcareous, with large *Belemnites*, *Rhynchonella tetrahedra*, *Terebratula* and *Pteria*	7 9	159 1
Middle and Lower Lias (*clays*)—		
Clay, dark and pale grey. A few nodules in the lower part	75 0	234 1

[1] From the Frodingham Iron and Steel Co., Ltd.

[2] For detailed sections of these shafts see 'Geology of North Lincolnshire' (*Mem. Geol. Surv.*), 1890, pp. 214-6.

[3] For detailed section of the borehole see 'Geology of North Lincolnshire' (*Mem. Geol. Surv.*), 1890, p. 212.

[4] *Op. cit.*, p. 213.

	Thickness. Ft. Ins.	Depth. Ft. Ins.
Pecten Bed—		
Limestone, pale brownish-yellow, oolitic and ferriferous, in part rather sandy. The ooliths have a yellowish-brown crust, but are white inside. Large ribbed *Pecten*, large smooth *Pecten*	2 10	236 11
Lower Lias (*clays continued*)—		
Clay, dark and shaly	31 2	268 1
Stone, brittle, grey	0 3	268 4
Clay, dark and shaly	66 8	335 0
Shale, dark-grey, with some pyrites. In the lower part numerous upper valves of a small *Gryphaea* with occasional rolled fragments of the thicker lower valve; also a small *Belemnites*	1 1	336 1
Frodingham Ironstone—		
Clay, dark and calcareous, with patches of brown ferruginous ooliths	0 1	336 2
Dark grey calcareous and micaceous clay with irregularly alternating layers crowded with ferruginous ooliths, so that the whole has a streaky appearance: occasional *Belemnites*, small *Pecten* and a few small *Gryphaea* ...	1 0	337 2
Light grey shelly, unevenly oolitic, ferriferous limestone passing down into	0 1	337 3
Brown, densely oolitic calcareous ironstone: layers of small shells including a small smooth *Pecten*	0 6	337 9
Greenish-grey hard compact limestone, very slightly oolitic; many small *Gryphaea*, &c.	0 2	337 11
Greenish-grey softer more or less densely oolitic poorly ferriferous limestone, the ooliths usually hollow and crushed: a few fragmentary shells	3 6	341 5
Dark greenish-grey and brown bands alternating, both full of polished brown ooliths in a clayey matrix	1 0	342 5
Dark brown, harder more or less densely oolitic ironstone, with polished ooliths of lighter brown colour in a marly matrix: few small *Gryphaea*	1 11	344 4
Dark green speckled pyritous and aluminous limestone, sparsely oolitic ("sulphur-bed")	0 10	345 2
Brown and dark greenish-grey ironstone, with alternation of bands full of brown polished ooliths and dark bands sparsely oolitic and more calcareous	1 7	346 9
Brown and greenish-grey streaky more and less densely oolitic ferriferous limestone, with large calcitic *Cardinia*-shells, some green-coated	0 2	346 11
Similar stone without *Cardinia*	1 2	348 1
Brown densely oolitic ironstone, with polished brown ooliths in a dark green matrix of ferrous carbonate: occasional small pyritous nodules: bottom band rather calcareous ...	1 6	349 7
Similar stone, without calcareous bands ...	0 10	350 5
Frequent alternations of brown densely oolitic, somewhat calcareous ironstone and pale grey poorly ferriferous limestone with a few brown ooliths	4 2	354 7
Soft brown densely oolitic ironstone with a dark green matrix of ferrous carbonate ...	0 6	355 1
Similar stone with calcareous shelly bands and thin clay partings	0 8	355 9

	Thickness. Ft.	Ins.	Depth. Ft.	Ins.
Soft brown densely oolitic ironstone with a dark green matrix of ferrous carbonate	0	11	356	8
Brown reddish and greenish, rather densely oolitic ferriferous limestone with green and red matrix: many calcareous shells, including small ribbed and smooth species of *Pecten* and at the bottom a band of green-coated *Cardinia*	1	10	358	6
Brownish and greenish-grey oolitic ferriferous limestone with less densely aggregated brown ooliths in a pale greenish calcareous matrix: an irregular band of dark green shale near top	0	9	359	3
Reddish oolitic ferriferous limestone: ooliths not very densely aggregated, but many of them larger than usual and of irregular shape: numerous *Cardinia*-shells filled with crystalline calcite: some calcite veins	1	0	360	3
Brown densely oolitic ironstone, with polished brown ooliths in a green matrix of ferrous carbonate, becoming calcareous in lower part with limestone-bands and a few large calcitic shells	1	2	361	5
Yellowish-brown densely oolitic ironstone, with decomposed yellowish-brown ooliths in a green carbonate matrix, partly oxidized ...	1	5	362	10
Yellowish-brown densely oolitic ironstone, harder and much more calcareous	0	4	363	2
Brown densely oolitic ironstone, with yellowish-brown ooliths in a matrix largely oxidized to brown limonite	0	10	364	0
Hard red, green and brown blotchy less densely oolitic ferriferous limestone, with shells filled with calcite and some calcite veins: also green muddy patches and partings; a small ribbed *Pecten* in lowest part	1	6	365	6
Lower Lias (clays continued)—				
Hard dark green calcareous shaly marl, very finely sandy, with some mica and a few brown ooliths darker and more shaly in its lower part: a small ribbed *Pecten* and small *Gryphaea* of *G. cymbium* type	1	9	367	3
Dark more and less calcareous shale, with *Gryphaea* cf. *arcuata* in upper part	1	6	368	9
Dark grey muddy more or less ferriferous limestone with numerous brown ooliths ...	1	3	370	0
Similar limestone, more muddy and somewhat shaly	0	3	370	3
Light and dark grey shale, more and less calcareous: some imperfect specimens of a small *Gryphaea* suggest *G. cymbium* type: a small ribbed *Pecten*	3	3	373	6
Similar dark shale with small species of *Pecten*, smooth and ribbed	0	8	374	2
Hard compact crystalline pale brownish-grey limestone, slightly oolitic	0	4	374	6
Rather hard grey calcareous shaly marl, with small ribbed *Pecten*	0	2	374	8
Hard grey and brownish calcareous marl with small *Pecten* and large *Gryphaea* (*G. arcuata*?) [lowest core]	0	11	375	7
Dark clay	3	11	379	6
Hard limy stone	0	5	379	11
Shelly clay	1	7	381	6
[bottom of borehole.]				

The depth, thickness and average iron-content of the Frodingham Ironstone as proved in the Appleby borings,[1] the first four in order from north to south, are as follows:—

No. of Borehole.	Depth to top of Frodingham Ironstone.	Complete thickness of Ironstone-bed	Thickness of usable Ore.	Average Iron in Raw Ore.			
				Whole bed.		Usable Ore.	
				Moist.	Dried.	Moist.	Dried.
	Ft. Ins.	Ft. Ins.	Ft. Ins.	per cent.	per cent.	per cent.	per cent.
2	239 11	32 4	—	18·77[2]	20·73[2]	—	—
4	240 2	28 9	17 4	20·68	23·04	23·3	26·1
3	288 8	28 0	21 5	21·78	24·77	23·09	26·99
1	336 1	29 5	—	19·89	22·06	—	—
5	266 4	26 8	14 6	20·09	22·27	23·2	26·0
6	264 4	29 7	—	19·3	21·03	—	—

These borings constitute the only evidence available for estimating the quality of the ironstone at a distance from its outcrop.

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[1] From the Appleby Iron Co., Ltd.

[2] In No. 2 Borehole, parts of the cores, amounting to 9 ft. 8 ins., and representing the softer and perhaps better portions of the ore, were lost in boring.

CHAPTER V.

MARLSTONE (MIDDLE LIAS) ORES OF LINCOLNSHIRE, LEICESTERSHIRE, NORTHAMPTONSHIRE, OXFORDSHIRE, AND WARWICKSHIRE.

By C. B. Wedd and J. Pringle.

Lincolnshire and Leicestershire:—Stratigraphical Description.

The Marlstone ore occupies a well-defined stratigraphical position at the top of the Middle Lias, where it forms the upper member of the Marlstone Rock-bed. This rock-bed, where well developed, consists of a fairly massive more or less calcareous sandstone in its lower part, passing upward into a ferriferous oolitic limestone, which weathers to a rich brown ferruginous deposit. Both the lower sandstone of the Rock-bed and the overlying ferriferous oolite or ironstone vary greatly in thickness and in parts of the Middle Lias outcrop almost or completely disappear. In Lincolnshire and Leicestershire the ironstone occurs as a workable ore only where the whole rock-bed, which attains a maximum thickness of about 40 feet[1] in Leicestershire, is fairly well developed.

When the ironstone is present, the normal sequence is:—

Upper Lias		Dark blue clays, usually pale near the base ...	90 ft. to 190 ft.
Middle Lias.	Marlstone (*Spinatus* zone).	Ferriferous oolitic limestone or ironstone ...	up to 16 ft.
		Calcareous sandstone ...	up to about 25 ft.
	Middle Lias Clays (*Margaritatus* zone)	Pale clays, sandy and calcareous, with calcareous nodules ...	——

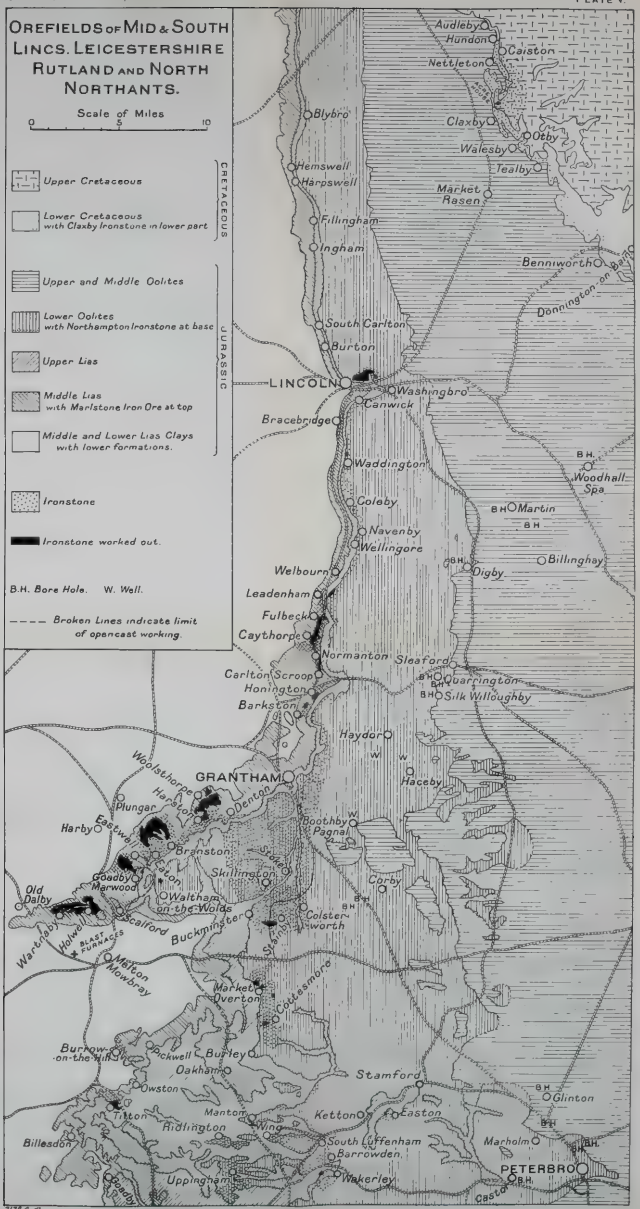
The full thickness of the Marlstone ore in its working-area ranges from about 7 feet to probably about 12 feet in Lincolnshire, and from about 9 feet to about 16 feet, with an average of perhaps 12 feet, in Leicestershire. But owing to the conditions of surface weathering, under which alone this ironstone becomes a valuable ore in the East Midlands, the complete thickness is frequently not present in the workings.

The lower limit of workable ore is fixed as a rule rather definitely by a sudden downward change to the calcareous or decalcified sandstone of the rock-bed, this sandstone being used locally as a building-material.

In North Lincolnshire the Marlstone Rock-bed, described as a hard light-grey limestone, weathering brown, and containing abundant *Rhynchonella tetrahedra*,[2] is recognizable in the same

[1] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 40.

[2] Rev. J. E. Cross, 'The Geology of North-West Lincolnshire,' *Quart. Journ. Geol. Soc.* (1875), p. 120.


OREFIELDS OF MID & SOUTH LINCS. LEICESTERSHIRE RUTLAND AND NORTH NORTHANTS.
Scale of Miles
0 5 10
CRETACEOUS
Upper Cretaceous
Lower Cretaceous with Claxby Ironstone in lower part
JURASSIC
Upper and Middle Oolites
Lower Oolites with Northampton Ironstone at base
Upper Lias
Middle Lias with Marlstone Iron Ore at top
Middle and Lower Lias Clays with lower formations.
Ironstone
Ironstone worked out.
B.H. Bore Hole. W. Well.
Broken Lines indicate limit of opencast working.
Audleby
Hundon
Caistor
Nettleton
Blyborough
Claxby
Otby
Walesby
Tealby
Hemswell
Harpswell
Market Rasen
Fillingham
Ingham
Benniworth
Donnington on Bain
South Carlton
Burton
LINCOLN
Washingboro
Canwick
Bracebridge
Waddington
Woodhall Spa
Martin
Coleby
Navenby
Wellingore
Billinghay
Digby
Welbourn
Leadenham
Fulbeck
Caythorpe
Normanton
Sleaford
Carlton Scroop
Barrington
Silk Willoughby
Honington
Barkston
Haydor
GRANTHAM
Woolsthorpe
Harlaxton
Denton
Plungar
Harby
Eastwell
Boothby Pagnell
Haceby
Branston
Skillington
Corby
Goadby Marwood
Old Dalby
Waltham on the Wolds
Colsterworth
Scalford
Buckminster
Stainby
Wartnaby
Holwell
BLAST FURNACES
Melton Mowbray
Market Overton
Cottesmore
Burrow on the Hill
Ashwell
Burley
Oakham
Owston
Stamford
Glinton
Tixover
Manton
Wing
Ketton
Easton
Ridlington
Billesdon
South Luffenham
Barrowden
Marholm
PETERBRO
Uppingham
Wakerley
Castor

position as the Cleveland and Leicestershire ores. As represented in the cores from a bore-hole ½ mile south of Appleby Station, it is a pale grey calcareous sandstone, about 7 feet thick, without any trace of ironstone; but farther south, from Cleatham to Kirton Lindsey, where its outcrop makes a distinct feature, it is composed of rubbly ferruginous limestone, 8-10 feet thick.[1] It 'has been quarried in places between Kirton and Manton. The rock is here and there nodular, but nowhere rich enough in iron to be of value for smelting.'[2] It appears, however, to have been the Marlstone Rock-bed, rather than the Pecten Bed, for which an output has been recorded of about 3,400 tons of iron-ore from Kirton Lindsey between 1860 and 1862.[3] Southward, the whole bed fails beyond Burton, near Lincoln, but reappears farther on.[4] The ironstone, of which some representative has been found at Welbourn,[5] first comes in as a workable ore near Leadenham 14 miles south of Lincoln, and extends thence southward by Fulbeck and Caythorpe to Honington and Barkston, beyond which excessive denudation of its outcrop has rendered it commercially worthless for several miles (*see* map, Pl. V). It recovers its thickness and quality at Woolsthorpe and Denton on the Lincolnshire border, whence it passes south-westward into Leicestershire, and continues, with considerable interruption, in broad tracts of good ironstone to Holwell and Wartnaby.

Along the south side of the great westward spur of Marlstone and higher strata that extends to Old Dalby and Grimston, a thick sheet of Glacial drift for several miles first eastward and then south-westward, generally conceals the Rock-bed,[6] which, on the whole decreasing in those directions, is scarcely exposed in all that distance except in the valley between Wymondham and Whissendine. There, however, where the Marlstone, greatly reduced in thickness, still makes an escarpment, no workable ironstone has been found.

At Pickwell, 8 or 9 miles south-east of Wartnaby, the Marlstone emerges from its covering of drift, and remains more or less bare of cover for about 7 miles south-westward. The ore has been proved at Burrow-on-the-Hill, and is worked at Tilton; but this section of the outcrop seems not to have been thoroughly explored.

However, from Billesdon southward the whole Rock-bed, including the ironstone, diminishes and locally almost disappears. In passing through South Leicestershire and the western part of Northamptonshire into Oxfordshire, the Marlstone may be considered of no value as a source of iron until it enters the Daventry district.

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[1] 'Geology of North Lincolnshire' (*Mem. Geol. Surv.*), 1890, p. 53.

[2] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iii, 1893, p. 243.

[3] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

[4] E. Wilson, 'The Lias Marlstone of Leicestershire as a source of Iron,' *Mid. Nat.*, vol. viii, 1885, p. 97.

[5] 'Geology of South-west Lincolnshire' (*Mem. Geol. Surv.*), 1885, p. 40.

[6] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 40: 'Geology of Leicester' (*Mem. Geol. Surv.*), 1903, p. 30.

The Ore-bed in Lincolnshire and Leicestershire.

The Marlstone ore in its unweathered state is a bedded deposit of green ferriferous and oolitic limestone, consisting mainly of carbonates, with some silicates, of lime and iron. In this state it varies in appearance from a dark green densely oolitic stone, with dark green ooliths crowded in a still darker matrix, where the stone makes the richest ore, to a lighter green less densely oolitic material containing much calcite and usually large clusters of brachiopods and other shells. "Kernels and occasionally thin beds of bluish-grey or greenish worthless stone . . . . occur in the body of the ore. Under the microscope these are found to consist of organic fragments set in a matrix of colourless crystalline carbonate."[1]

But in the state in which it is quarried as iron-ore in Leicestershire and Lincolnshire, the bed has been changed by oxidation and solution under surface-conditions either completely or mainly into a rich brown soft decalcified ironstone, still retaining its oolitic structure, in which the closely packed ooliths, converted into ferric oxide, are bound together by a cement of the same material. In most quarries in which the whole thickness of the ore is present the change is not complete, one or more beds, especially in the lower part, retaining unaltered green cores; but in many workings where denudation has somewhat diminished the thickness of the bed, all the remaining thickness is thoroughly decalcified. From this state there is every gradation to that in which the ore, on passing under thin cover, is decalcified and weathered brown merely at the top and along bedding- and joint-planes where percolation has taken place. In an exceptional tract at Fulbeck, near the north end of the workable area in Lincolnshire, the upper half of the bed consists regularly of a light yellowish brown flaggy ferriferous limestone, while the lower half is a brown weathered ore. In this case the upper half was no doubt originally composed of denser and less oolitic limestone than usual.

Some deposition of ferric oxide in joints and cracks locally recalls the early stages of the 'box-structure' so characteristic of the weathered Northampton Ironstone (*see* p. 143). But the absence of anything like the complete development of this structure at once differentiates the Marlstone from the Northampton ore in the weathered state.

Joint-faces of the oxidized Marlstone ore often exhibit a bluish-black film of oxide of manganese, as do locally those of the Frodingham and other Jurassic ores. But the amount of such manganese is so small as to produce no appreciable effect on the chemical analysis of the ore.

In the thoroughly weathered state of this ironstone even the calcite shells of brachiopods and guards of belemnites have been completely dissolved and all fossils are represented merely by casts or hollow moulds.

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[1] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 91: see also 'Jurassic Rocks of Britain,' (*Mem. Geol. Surv.*), vol. iv, 1894, pl. ii and p. 28.

Its fossil-contents[1] serve readily to distinguish this ore from the Northampton and Frodingham Ironstones. The Marlstone ore almost everywhere contains great quantities of the highly characteristic brachiopods *Rhynchonella tetrahedra* (Sow.) and *Terebratula punctata* (Sow.), commonly aggregated in large clusters. The belemnites *Belemnites elongatus* (Miller) and *B. paxillosus* (Schloth.) also occur in large numbers. Other characteristic fossils are the lamellibranchs *Modiola scalprum* (Sow.), *Pecten æquivalvis* (Sow.), *P. liasianus* (Nyst.), *Protocardia truncata* (J. de C. Sow.), and *Pteria (Oxytoma) inæquivalvis* (Sow.) The zone-ammonite *Paltopleuroceras spinatum* (Brug.) is rarely found in the district.

The abundance of belemnites[2] and of the above-mentioned brachiopods affords a useful means of distinguishing this ironstone from the Northampton ore; while the absence of anything like the Cardinia-beds of the Frodingham Ironstone from the Marlstone ore and of brachiopod-clusters from the Frodingham ore readily differentiates those two ironstones.

Conditions affecting the Ore.

The Marlstone of Lincolnshire and Leicestershire has on the whole a slight eastward dip with minor local variations. The Rock-bed, usually a massive deposit resistant to denudation, where the ironstone is well developed, overlies a great thickness of soft and easily eroded clays of the Middle and Lower Lias, above which it rises in an escarpment gradually falling eastward with the dip. The ironstone in turn is overlain by a considerable thickness of soft Upper Lias clay, followed by the resistant masses of the Northampton Sand and of the Lincolnshire Limestone, where present. These resistant masses protect the Upper Lias clay and control the rate of recession of its outcrop in the process of denudation.

In the typical area of the Leicestershire ironfield a long and gentle dip-slope of the ironstone-bed has thus gradually been exposed to atmospheric influence; the ore has to a great extent been oxidized by weathering and relatively enriched by the removal of carbonate of lime in solution. Moreover, the drainage is mainly eastward down the dip-slope, until it is held up and diverted by the Inferior Oolite escarpment; and, farther, there is a large amount of iron disseminated throughout the thick clay of the Upper Lias. Much of this iron, set free on the weathering and denudation of the clay, must have percolated downward into the absorbent ironstone-bed below, which has thus received a

[1] Fossil-lists are given in appendices to 'Geology of the South-Western Part of Lincolnshire,' 1885, and 'Geology of Leicester,' 1903 (*Mem. Geol. Surv.*), and by E. Wilson, 'The Lias Marlstone of Leicestershire,' *Mid. Nat.*, vol. viii, 1885, p. 156; also in 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iii, 1893, App. But most of these lists include ammonites foreign to the Marlstone proper (as limited to the zone of *Paltopleuroceras spinatum*) and confined to a local top bed consisting of a very few inches at the most of a somewhat different limestone. In Wilson's paper, the faunal difference between the Marlstone Rock-bed and this thin top bed is emphasized. Cp. sections, pp. 119, 135, below.

[2] *See* 'Geology of Rutland' (*Mem. Geol. Surv.*), 1875, p. 65.

greater enrichment than is due merely to concentration by oxidation of ferrous carbonate and removal of calcium carbonate in solution.

The Marlstone ore of Leicestershire and Lincolnshire is rather poor in iron in its unweathered carbonate state, and becomes profitable to work only where it has been enriched under atmospheric influence. For on approaching the cover of Upper Lias clay it becomes suddenly more calcareous and less ferriferous, and this deterioration continues as it passes under the clay.[1] Consequently it is worked only at the surface in this district, or under a maximum thickness of about 17 feet of cover, where Upper Lias clay is present. Under even that thickness it becomes so highly calcareous that it probably would not be worked unless required as ferric lime for fluxing the richer weathered ore into which it passes at the surface. Possibly, however, in some parts of the district the unweathered Marlstone ore might at some future time repay mining as ferric lime for mixing with richer siliceous ore from the same part of the country.[2]

A similar limitation of quality prevails apparently throughout the south of England wherever this ore is worked; but not in Cleveland, nor in the Isle of Raasay,[3] in both of which districts the ironstone-bed is richer in iron before coming under atmospheric influence.

In the principal area of the Marlstone ore in the East Midlands, the tract extending from Woolsthorpe and Harston on the Lincolnshire border, south-westward to Holwell and Wartnaby in Leicestershire, the Marlstone Rock-bed, here attaining its maximum thickness, makes a bold escarpment above the soft clays eroded in the broad excavation of the Vale of Belvoir, and has a long dip-slope, on which the ironstone occupies a broad surface-area and is on the whole well weathered. In this area the ore is at its best.[4]

But farther north, in Mid Lincolnshire, the Rock-bed has diminished, with less prominent escarpment; its dip-slope is shorter and the ironstone-outcrop narrower, while the ore is on the whole less weathered and more calcareous, besides being less regular in its distribution as a workable ironstone (cp. Pl. VI, Sects. 1 and 2).

Moreover, from the Leicestershire border for some distance north-eastward the valleys of the Witham and its tributaries have cut off and so much dissected the denuded outcrop of the ironstone, there not otherwise reduced in width, that only thin scattered remnants of the ore-bed, too small to repay separate working, remain upon the lower sandy beds between Woolsthorpe and Barkston (*see* Map, Pl. V).

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[1] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, pp. 45, 91.

[2] *See* E. Wilson, *op. cit.*, p. 126, who records an iron-percentage of 25—30 in samples of unweathered ironstone from the Tilton workings. These figures presumably refer to dried ore as worked in the quarry under merely thin cover

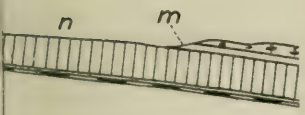
[3] The Raasay Iron-ore belongs palæontologically to the Upper Lias: but lithologically and stratigraphically as overlying the Marlstone Rock-bed, it represents the Marlstone ore of England: i.e., the same conditions of deposition as in England extended rather later to the West of Scotland.

[4] For a description of this area *see* 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 40.

D EAST THROUGH THE I

Cranwell

ONE OF UNCERTAIN QUALITY



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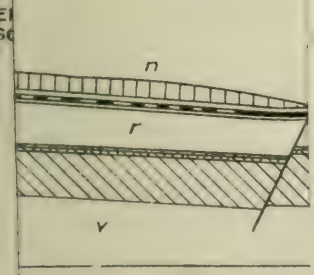
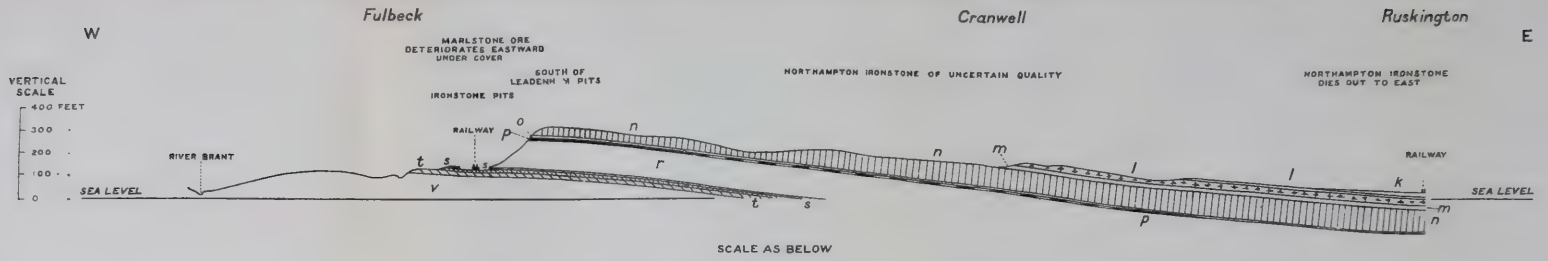


Inferior Oolite
od

From Ores, Vol. III. (see Key p. 190)

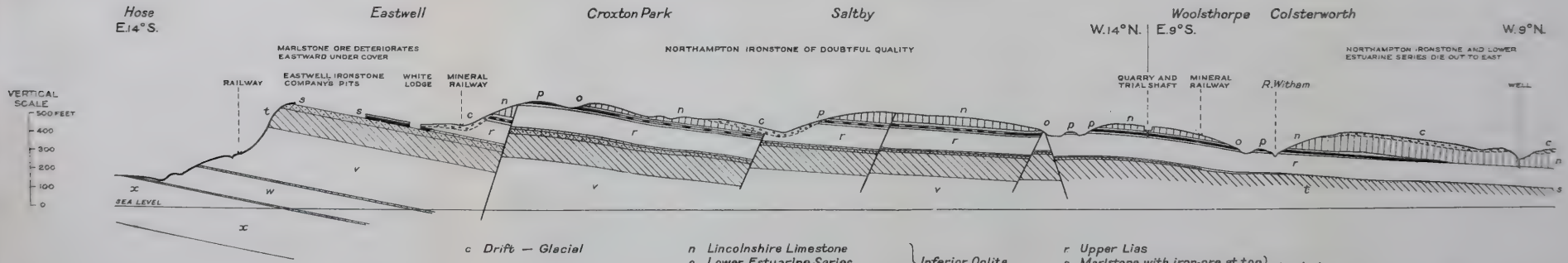
SECTION 1.– ACROSS THE JURASSIC ORE-FIELDS OF MID LINCOLNSHIRE, FROM WEST TO EAST THROUGH THE IRONSTONE-PITS OF FULBECK.



- *k* Oxford Clay with Kellaways Beds at base
- *l* Great Oolite Series with Cornbrash at top
- *m* Upper Estuarine Series
- *n* Lincolnshire Limestone
- *o* Lower Estuarine Series
- *p* Northampton Ironstone and Sand } Inferior Oolite Series
- *r* Upper Lias
- *s* Marlstone with Iron Ore at top
- *t* Clay
- *v* Lower Lias } Middle Lias

Marlstone and Northampton Ironstones shewn by thick black lines

SECTION 2.– ACROSS THE JURASSIC ORE-FIELDS OF LEICESTERSHIRE AND SOUTH LINCOLNSHIRE, FROM NEAR EASTWELL TO NEAR COLSTERWORTH.



- *c* Drift — Glacial
- *n* Lincolnshire Limestone
- *o* Lower Estuarine Series
- *p* Northampton Ironstone and Sand } Inferior Oolite
- *r* Upper Lias
- *s* Marlstone with iron-ore at top
- *t* Clays
- *v* Lower Lias
- *w* Semicostatus zone of Lower Lias with thin limestones (= horizon of Frodingham Ironstone)
- *x* Lower Lias } Middle Lias

Marlstone and Northampton Ironstones shewn by thick black lines

2170 A 19

In the minor southern ironstone-working tract of Leicestershire the Rock-bed, maintaining a diminished thickness of 18 or 19 feet from Pickwell to Billesdon, again rises into conspicuous escarpments and forms bare elevated plateaux or long gentle dip-slopes,[1] on which serviceable ironstone occurs at Burrow-on-the Hill. At Tilton, however, the weathered stone owes its quality rather to the erosion of a transverse valley which has produced the same effect of long exposure, but without the same width of outcrop. Thinning south-eastward from Billesdon, the Rock-bed still retains its relative elevation and its escarpment as far as Goadby, though reduced to a few feet of hard flags protecting the underlying clay.[2] From the neighbourhood of Billesdon southward the ironstone appears to fail for many miles.

Chemical Composition.

The following tables give the average values of the chief chemical constituents of the Marlstone ore in Leicestershire and Lincolnshire, as well as typical analyses of that ore for the two counties. Apart from the ironstone of Woolsthorpe and Denton, which, lying on the border of Lincolnshire, belongs naturally to the Leicestershire area and is included with it in the tables, the Marlstone ore of Lincolnshire is almost entirely such as would be classed as 'limy' in Leicestershire; consequently no separate figures are given for siliceous ore in Lincolnshire; but for the Leicestershire ore separate columns are assigned to the 'siliceous' or 'soft' and the 'calcareous' or 'limy' varieties into which the ore is always divided:—

Marlstone Iron-ore of Leicestershire and Lincolnshire.

Raw Ore.	Average values of chief chemical constituents.			Typical analyses.		
	Leicestershire including Woolsthorpe and Denton.		Lincolnshire.	Leicestershire including Woolsthorpe and Denton.		Lincolnshire.
	Siliceous or soft ore. per cent.	Calcareous or limy ore. per cent.	Calcareous or limy ore. per cent.	Siliceous or soft ore. per cent.	Calcareous or limy ore. per cent.	Calcareous or limy ore. per cent.
Iron, 'as received' ...	25·5	23·7	25·1	25·47	23·50	23·80
Iron, dried at 100° C.	33·2	29·4	28·6	33·38	28·66	29·60
Silica, 'as received' ...	12·1	10·9	10·0	12·41	10·50	8·60
Alumina ,, ...	8·2	7·4	4·7	9·30	6·15	4·42
Lime ,, ...	2·9	13·5	17·0	2·04	10·10	27·40
Magnesia ,, ...	·6	·7	3·0	·44	·70	9·47
Manganese ,, ...	·2	·3	·3	·21	·32	·34
Sulphur ,, ...	·1	·1	·2	·12	·05	·30
Phosphorus ,, ...	·3	·5	·5	·29	·32	(not est.)
Moisture ,, ...	23·2	19·0	12·2	27·0	18·00	11·20
Loss on ignition	—	—	—	12·84	—	29·60

The chief difference between the siliceous or soft and the calcareous or limy ores, *i.e.*, between the more and the less completely

[1] 'Geology of Leicester' (*Mem. Geol. Surv.*), 1903, pp. 31-2.
[2] *Op. cit.*, p. 34.

weathered conditions of the same ore, is that the former contains decidedly more iron, silica and alumina, and that in it moisture largely replaces the lime and magnesia of the calcareous ore.

A comparison with other Jurassic ironstones shows that even the highly calcareous Marlstone ore of Lincolnshire has a higher average iron-percentage than the Frodingham stone, than which it contains much less manganese. The siliceous variety of the Marlstone ore, with an average iron-content decidedly below that of the Northampton Ironstone, contains rather less phosphorus, but rather more sulphur.

The Marlstone ore, as suggested by the blast-furnace classification into siliceous and calcareous varieties, has a much wider range of variation than the Northampton, and for practical purposes even than the Frodingham ore, in which calcareous and decalcified beds alternate and interchange too frequently for ready separation in practice.

From the conditions already described as governing the variation of the Marlstone ore between calcareous and decalcified or siliceous states, it follows that these two varieties, though merging into one another, have each a more or less definite distribution. The ore on the outer parts of the outcrop farthest from the cover of Upper Lias clay is the more decalcified, and at the same time less in thickness and less constant owing to partial denudation; while before reaching the edge of the Upper Lias it becomes rapidly more calcareous, but tends to regain its full thickness.

Consequently, as the best siliceous ore, which has on the whole been worked most and longest, approaches exhaustion in the principal areas, the stone remaining to be worked must become more calcareous in average composition.

Faults and 'Wash-outs.'

On the whole a general freedom from serious faulting characterizes the Marlstone area as well as those of the other Jurassic ironstones of the eastern counties. An east-and-west fault with northerly downthrow of no great amount is represented on the one-inch geological map as crossing the outcrop less than a mile south of Barkston. At Eastwell a system of close parallel step-faulting with small north-easterly downthrows and sharp intermediate dips in the opposite direction continues a belt of similar step-faulting in the same direction more than a mile away to the south-east at White Lodge[1]. But at Eastwell it appears to culminate on the north-east side in a large fault which cuts off the ironstone. North of Holwell an east-and-west fault with southerly downthrow cuts out the ironstone on the north side, and other small faults were proved in the neighbourhood of Holwell and Wartnaby.

In the case of an ore-bed dependent for its quality upon the effects of denudation, any inequality of dip or of erosion may result in areas of barren ground where the base of the bed has

[1] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 46. For similar step-faulting in the Northampton Ironstone *see* below, p. 145.

been brought to the surface. The Marlstone tract of Leicestershire shows many examples of this, where the ore thins out at the surface and is replaced by the lower sandy beds. These, sometimes termed 'wash-outs,' seem appreciably to have diminished the output of ore in relation to the area worked (*see* below, p. 114).

Less important are pockets of Upper Lias or Glacial clay let down into the ironstone along weathered joints or other disturbances, or in mere erosion-cavities.[1]

History and Development.

Like the Frodingham and Northampton Ironstones, the Marlstone ore was known and worked in Leicestershire and Rutland as a source of iron in early times, as is proved by the occasional discovery of ancient slags. In recent years the regular working of this ore began somewhat later than that of the other two ironstones. In 1855 Marlstone ore from Croxton, Leicestershire, was tried in the furnaces of the Clay Cross Company, but owing to transport difficulties no farther steps were taken.[2]

In 1873 Mr. R. Dalgliesh decided to work the ore at Holwell, and the Holwell Iron Company, formed for this purpose, began to work it in 1875; but it is not until 1880 that any output of Marlstone ore from Leicestershire or Lincolnshire figures in the extant statistics. In that year outputs of 77,638 tons and 52,387 tons of ore are recorded from Caythorpe (Lincolnshire) and Old Dalby (Leicestershire) respectively[3], the latter amount coming presumably from Wartnaby. The Holwell Company's Astordby furnaces were erected in 1881.[4] In 1882 the ore was being worked both at Holwell and at Eastwell, and in 1884 at Harston,[5] so that ironstone-quarrying had by then extended throughout the length of the main orefield of Leicestershire.

The following figures[6] show for the first ten years a rapid increase of ironstone-output from Leicestershire, practically all Marlstone ore, and subsequently a much slower rate of increase, with fluctuations, the maximum output of 846,021 tons having been reached in 1913:—

Leicestershire Ironstone.

Year.	Output in tons.
1881	99,599
1885	310,529
1890	609,964
1895	598,401
1900	630,361
1905	691,614
1910	560,410 (incomplete).
1915	685,137

For Lincolnshire no separate statistics of Marlstone ore are available.

[1] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 48.

[2] E. Wilson, 'The Lias Marlstone of Leicestershire as a source of Iron,' *Mid. Nat.*, vol. viii. 1885, p. 61.

[3] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

[4] E. Wilson, *op. cit.*, p. 62.

[5] Home Office Records.

[6] From 'Mineral Statistics' and Home Office Records.

Content, Output and Reserves.

The area of the whole ironfield, so far as the ground containing good ore can be estimated, may be regarded as nearly 7 square miles in Leicestershire (without taking into account any possible extension in the south between Pickwell and Billesdon) and rather more than 3 square miles in Lincolnshire; of which the amount worked out is less than 3 square miles in Leicestershire, and about $1\frac{1}{3}$ square miles in Lincolnshire; so that reserve areas of rather more than 4 square miles and less than 2 square miles respectively remain in the two counties (*see* map, Pl. V).

Since the Marlstone ore of these counties depends so largely on atmospheric action for its quality, most of the ore already removed or remaining to work falls in point of thickness below the average of the whole bed, as the result of denudation. While in a few cases the full maximum thickness of 15 or 16 feet may be got, though rarely without rejection of some excessively calcareous parts, elsewhere remnants of good weathered ore may be worked with a maximum thickness of no more than 3 feet. Consequently the average thickness of stone worked becomes difficult to ascertain, and since the more weathered and better tracts have been worked more extensively than the less weathered and less denuded areas, the thickness of the stone worked out varies more, owing to inequality of denudation, than that of the stone remaining, and its average must be less.

The total output of Marlstone ore for Leicestershire in the period from 1880 to 1916 inclusive, as determined by the available statistics,[1] amounts to rather less than 20,300,000 tons, and may be estimated from the corresponding data to have been probably not more than 10,000,000 tons for Lincolnshire in the same period. For in recent years the Leicestershire output of Marlstone ore has greatly exceeded the Lincolnshire output of the same ore (in 1917 Leicestershire produced 554,591 tons and Lincolnshire 381,628 tons—total 936,219 tons[2]); but in the early years of the industry the Lincolnshire output may have been the greater. The total estimates given above imply, if the statistics are complete, a rather small average thickness of serviceable ore obtained from the areas exhausted, viz., about 5 feet 3 inches for Leicestershire and 5 feet 10 inches for Lincolnshire—considerably less, in the case of Leicestershire, than the average thickness of good ore in the working-faces; for the areas worked out include tracts of barren ground or of thin ore, as the result of uneven denudation or of local deterioration, *e.g.*, at Wartnaby, Holwell and north of Eaton.

As already stated, the areas of Marlstone ore remaining to be worked in these counties should contain ironstone of greater average thickness with less barren ground, but on the whole more calcareous. On assumed average working-thicknesses of 8 feet of ore for Leicestershire and 7 feet for Lincolnshire, the reserves

[1] 'Mineral Statistics of the United Kingdom' for the first two years, and subsequently the Home Office Records.

[2] From the Ministry of Munitions. The Stanton Company's Harston workings, situated on the Leicestershire side of the county boundary, are here included under 'Lincolnshire.'

of Marlstone ore would amount to about 42,000,000 tons and less than 20,000,000 tons respectively for the two counties[1]; so that the total content of workable Marlstone ore before working began may be considered to have been not less than 62,000,000 tons in Leicestershire, and about 30,000,000 tons, or rather less, in Lincolnshire. Possibly these latter figures should be increased by a not inconsiderable amount of calcareous ore that could have been utilized under present conditions, but was wasted as of no value, in extracting the ore under earlier conditions.

The map, Plate V, shows the distribution of the reserves estimated and of the principal areas worked out. At Leadenham, the most northerly point of former working, though workable ironstone may possibly extend a little farther north to Welbourn, it is probable that comparatively little Marlstone ore has been got, and a limited amount remains between there and Fulbeck, where the ironstone is now being worked along the more weathered part of its outcrop, west of the railway. It was formerly worked there east of the railway up to the outcrop of the Upper Lias, but was abandoned as too calcareous. Between Fulbeck and Caythorpe, at which place ironstone is still being got, chiefly west of the railway, the weathered outcrop on that side of the railway has been exhausted, but a narrow outcrop of more calcareous ore remains on the east side. It is stated that practically no serviceable ore remains between Normanton and Carlton Scroop, where operations have long since been discontinued. The ironstone, for the most part rather highly calcareous, is now being worked between Honington and Barkston in two quarries separated by a tract of barren ground, in which denudation has reduced the outcrop to very narrow dimensions. Workable ore has been proved for some little distance farther north on the east side of Honington. But south-westward from Barkston to the neighbourhood of Woolsthorpe and Denton, though the ground has been tested by trialing, only a few thin scattered remnants of the ore have been found, for reasons already indicated (*see* p. 110), on the broad outcrop of the Marlstone; while the ore-bed in the proximity of the Upper Lias becomes poor in iron and highly calcareous.

Woolsthorpe and Denton, both within Lincolnshire, may be taken to mark the beginning of that great tract of weathered Marlstone ore which extends beyond Wartnaby and constitutes the main orefield of Leicestershire.[2] This tract, however, is by no means continuous as a broad sheet of good weathered ironstone. The valley of the River Devon has cut deeply into it west of Woolsthorpe and Harston: and with its numerous tributaries has dissected it nearly as far as Eastwell, thus greatly

[1] These figures are less than the provisional estimates given in 'Summary of Progress' for 1917, p. 7; but in the case of Leicestershire they do not include any estimate of reserves in the Tilton district outside the ground actually proved, while in Lincolnshire any possible reserves on the outer parts of the Marlstone outcrop south of Caythorpe are excluded.

[2] For a detailed geological account of this ground *see* 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, pp. 41–9.

reducing the area of ironstone. At Eastwell a broad drift-filled depression traversing the outcrop makes a gap nearly a mile in width between the neighbouring areas of workable stone. Westward and south-westward from Goadby Marwood again denudation has almost entirely removed the profitable ore, and has left for the most part only the lower sandy beds at the surface, while near the outcrop of the Upper Lias the ore-bed appears to have been found too calcareous. This barren tract, intersected by a deep stream-valley and its tributaries, is cut off westward in the neighbourhood of Scalford by another broad depression filled with boulder-clay, under which one or more faults have the effect of narrowing the outcrop of the Marlstone. Near Holwell, however, the ore-bed comes to the surface again, and extends for 2 miles westward a little beyond Wartnaby, but not as a continuous area of ironstone. This area has been practically exhausted, only a small tract of good ore remaining at Wartnaby, where it is now being worked off. The Marlstone outcrop is prolonged about 2 miles farther westward, but except near its northward escarpment, is entirely covered with boulder-clay. Attempts to find workable ore on this westward prolongation have not proved successful. Apart from the small remnant at Wartnaby, work is now confined to the tract extending from Woolsthorpe to Goadby Marwood.

From Pickwell to Billesdon the elevated plateaux and gentle slopes of the Marlstone Rock-bed constitute an isolated area, which may prove to carry a greater extent of workable Marlstone ore than has yet been discovered there. For the conditions are similar to those prevailing in the other iron-producing Marlstone areas of Leicestershire and Lincolnshire (*see* above, p. 110). This tract of Marlstone, divided into two parts by a broad erosion-valley in the neighbourhood of Owston, may be estimated to contain a surface-area of the rock-bed amounting to about $2\frac{1}{3}$ square miles, in which the Marlstone, more or less intersected by stream-valleys, is free from cover of Upper Lias or of thick drift. While so far the ironstone has been worked only near Tilton Station, a mile east of the village, though it has recently been proved and leased at Burrow-on-the-Hill, the whole tract, from Pickwell to Billesdon, probably affords a better prospect than any other unexploited area in Lincolnshire or Leicestershire of an important extension of the Marlstone ore-fields. It has been said, however, that the ore south of Tilton is generally too thin to work.[1]

The extensive tract of low-lying ground extending southward from Wymondham and Whissendine beyond Oakham and Egleton contains a large area of the Marlstone Rock-bed, there exposed by valley-erosion. But the whole rock-bed, which has thinned considerably eastward, rarely attains a thickness of 9 feet, and is only 6 or 8 feet thick in the neighbourhood of Oakham.[2] The iron-ore, where present, is said to be too thin to work.[3]

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[1] Judd, 'Geology of Rutland' (*Mem. Geol. Surv.*), 1875, p. 70.
[2] *Ibid.*
[3] E. Wilson, *op. cit.*, p. 124.

Methods of Working.

In Leicestershire five companies, which either consume the ore in their own furnaces or are themselves owned severally or jointly by the great iron-makers of the North Midlands, now work all the Marlstone ore obtained. In cases of joint-ownership the ore from one quarry may go to more than one iron-producing district, and the proportions of siliceous and calcareous ironstone sent out can be adjusted to different requirements. In Lincolnshire, besides one of the same five companies, only two others are quarrying this ore, one of them raising it solely for sale and distributing it to several iron-makers chiefly, but not entirely, within the North Midlands.

The ore is necessarily worked wholly by opencast in these counties. The amount of cover varies from 1 or 2 feet of soil to a maximum, rarely reached, of 16-17 feet, where the proportion of Upper Lias clay is not great. In one exceptional case, as much as 22 feet of tough boulder-clay is being removed for a short distance, where no Upper Lias is present; and the ironstone is not much more calcareous under that amount of drift than in neighbouring ground where the drift-cover is thin.

In opencast working the soil is removed separately and is replaced on the new surface behind the working-face after filling in the excavation with the material of the cover and other waste.

Steam-navvies are sometimes used for removing the cover, but this is not the general practice. Occasionally tough boulder-clay requires blasting.

The ironstone is usually worked entirely by hand, rarely by steam-navvy. The stone is sometimes sorted by hand into 'limy' and 'siliceous' or 'soft' ore; but commonly a more or less definite division, either downward in depth, or horizontally in the direction of the outcrop of the overlying Upper Lias, enables the stone to be graded in bulk into siliceous and calcareous varieties.

In some workings a large proportion of very good ore is saved from the thin cover of weathered ironstone mixed with soil by shaking out with the fork. Occasionally this can be done where there is some admixture of boulder-clay; but in that case the stone saved is apt to be wet and dirty, and to require especial care in mixing. Where grading into the two varieties of ore is not possible or necessary, the whole thickness is usually worked together and mixed; but highly calcareous green cores are sometimes rejected as too poor in iron. In former years the lowest part of the ironstone, to a thickness of 3 or 4 feet, was in some cases left in the ground as too calcareous for use. The land being entirely agricultural, this ore was buried in re-making the ground, and is not now recovered. But such lower calcareous beds are nowadays worked together with the more decalcified parts.

The ore, never calcined at the quarries, for both the siliceous and the calcareous varieties, especially the latter, are commonly put into the blast-furnace in the raw state, is generally loaded at the 'face' into tubs hauled by a narrow-gauge engine either direct to the railway, where it is shot into trucks, or to a gravitation-plane leading down to the railway.

Railway facilities have naturally had an important bearing on the working of the ore. In this case the general parallelism of the Inferior Oolite and Marlstone escarpments in the north-and-south direction coincident with a main direction of railway traffic has given a fortuitous advantage in working the ore, owing to the natural suitability of the level ground at the foot of either escarpment for railway-construction. Thus all the main railways that now serve the ironstone-workings were in existence previously, only one standard-gauge mineral-line having been made since the beginning of the ironstone industry.

The Great Northern line northward from Grantham serves the Mid Lincolnshire workings: the main Leicestershire ironfield depends partly on the Grantham and Nottingham and the Melton and Nottingham lines, but mainly upon the G.N. and L. & N.W. Joint Line northward through Melton Mowbray, which line carries the ore also from the southern ironstone district of Leicestershire.

Treatment.

The chief seat of the iron-making industry based largely upon the use of Marlstone ore from Leicestershire and Lincolnshire, is the Derbyshire and Nottinghamshire coalfield (with an extension into South Yorkshire), where this and other Jurassic ores have displaced the Coal-measure ironstones formerly used. Only the Holwell Iron Company has its blast-furnaces in Leicestershire. This company had Marlstone ore close at hand, but since the exhaustion of the Holwell area now goes somewhat farther afield for its supply of Leicestershire ore.

Some of the Lincolnshire Marlstone ore goes to North and South Staffordshire, and recently some has been sent to Middlesbrough.

The calcareous Marlstone ore of Leicestershire, with an average lime-percentage of 12 or 13 and a little magnesia, is self-fluxing, but in mixture with the decalcified stone requires the addition of lime as a flux. It is probably owing partly to the decreasing proportion of siliceous Marlstone ore available that the general practice has arisen of mixing siliceous Northampton Ironstone with the Marlstone ore. For it was found that this was also well suited to the grades of iron made.

These have been in the past almost entirely foundry- and to a less extent forge-irons of good quality. Practically no pig for steel-making has been produced in the furnaces of the Derbyshire and Nottinghamshire Coalfield until recently. Even under

present conditions, when most of the companies that have depended largely upon the use of Marlstone ore are making basic iron for the manufacture of steel, as well as foundry- and forge-irons, these companies use principally a mixture of Northampton and Frodingham ores for steel-production, and still employ the mixture of Marlstone and Northampton ores, with the addition of limestone and in some cases of more calcareous ore as ferric lime, for making foundry- and forge-irons.

The limestone used is either Lincolnshire Oolite or, where the furnaces are conveniently situated for obtaining it, Derbyshire Carboniferous Limestone.

(2) Northamptonshire and Oxfordshire with Warwickshire.

Stratigraphical Description.

From South Leicestershire through much of Northamptonshire the Marlstone ore is of inferior quality, but about 4 miles south-west of Daventry in the latter county it again becomes productive. Thence it spreads south-westwards over a considerable area, lying chiefly in Oxfordshire, near Banbury, but including parts of Northamptonshire and Warwickshire.

The Rock-bed here consists mainly of a brownish-weathering ferruginous sandy oolitic limestone, passing down into brown sandy clays with thin hard calcareous bands. The bottom layers and the clays below contain numerous dark-skinned nodules. Eastwards the ironstone is overlain by Upper Lias clays and earthy limestones, and the thickness of this cover plays an important rôle in determining the quality of the ore.

The succession of strata is rarely displayed near Banbury, but some cuttings on a mineral-line recently made from the Great Western main line into the centre of the Edgehill plateau furnished the following details north and east of Neithrop Fields:—

Banbury and Edge Hill District.

		Ft.	Ins.
Upper Lias ...	Clay and limestone. At the base a 2-inch band of limestone (Acutum-bed), firmly welded on to the Marlstone	—	
Middle Lias ...	Marlstone Rock-bed: Thick-bedded sandy oolitic ferruginous limestone with large green cores ... ... 10 to	12	0
	Shales with small flattened dark-skinned nodules	9	0
	Bluish-grey sandy limestone, shaly at top ...	2	4
	Bluish-grey sandy micaceous clays with numerous white-skinned nodules	20	0
	Pale-grey sandy shelly limestone	2	9
	Dark-grey shelly micaceous clays	6	0
Lower Lias ...	Dark clay with brown-skinned nodules	seen	

The outcrop of the whole of the ferruginous Marlstone is shown as ironstone on the map forming Fig. 11 (p. 121). From Daventry southwards to near Banbury it forms a flat-topped belt of ground terminating in a short steep escarpment that overlooks the Lower Lias plain to the west. Eastwards it is covered by a gradually increasing thickness of Upper Lias and Oolites. In this outcrop the ore is mainly of the calcareous variety and contains an average iron-content of about 23 per cent. over the area regarded as workable. It is worked at Charwelton near Hellidon, at Byfield, and at Buston Farm near Kings Sutton, but deteriorates rapidly eastwards under the Upper Lias.

To the west and north-west of Banbury the outcrop widens out and the rock forms a long dip-slope rising from 300 feet above sea-level at Adderbury to upwards of 700 feet in the bold escarpment of Edge Hill. South-east of Edge Hill the rock-bed passes under a broad tract of Upper Lias and Oolites, and thence southwards forms only narrow outcrops. Here also it is principally calcareous, with an iron-content varying from 17 to 27·40 per cent., rising in places to 27·82 on a few parts of the dip-slope, but in others falling much below that figure. Prior to 1915 the principal workings were situated along the southern edge of the tract, at Hook Norton and Adderbury, but since that year openings have been made at Bloxham and Sydenham, near Adderbury, and arrangements are being made to develop the plateau between Edge Hill and Banbury, where the stone has hitherto been quarried for building only.

From this district southwards through Gloucestershire, Somerset, and Dorset, the stone consists of brown sandy ironshot limestone, of little value as a source of iron, though here and there layers may be found to yield a good percentage. It appears to have been formerly worked on Robin's Wood Hill, near Gloucester.[1]

In a working face the dip of the Marlstone is generally imperceptible, excepting near faults, but there is a general inclination of about 50 feet per mile towards the south-south-east, as shown by the dip-slope from Edge Hill to the River Cherwell.

Within the exposed ironfield the thickness of the Marlstone varies between 6 and 30 feet. It attains its maximum in the Edge Hill district and gradually diminishes to 6 feet in Northamptonshire. The attenuation appears to be due to the lower part passing into micaceous sandy clays with thin limestones. Consequently the ironstone of the eastern district is equivalent only to the upper portion of the Marlstone of Edge Hill. This thinning-out of the stone continues under the cover of Upper Lias and Oolites. Thus, in the section of the Brackley well,[2] the whole is represented by clay with beds of stone, while in boreholes at Calvert,[3] Burford,[4] and Oxford,[5] the Upper and Middle Lias are thin or

[1] P. B Brodie, *Quart. Journ. Geol. Soc.*, vol. ix, 1853, p. 31, footnote.

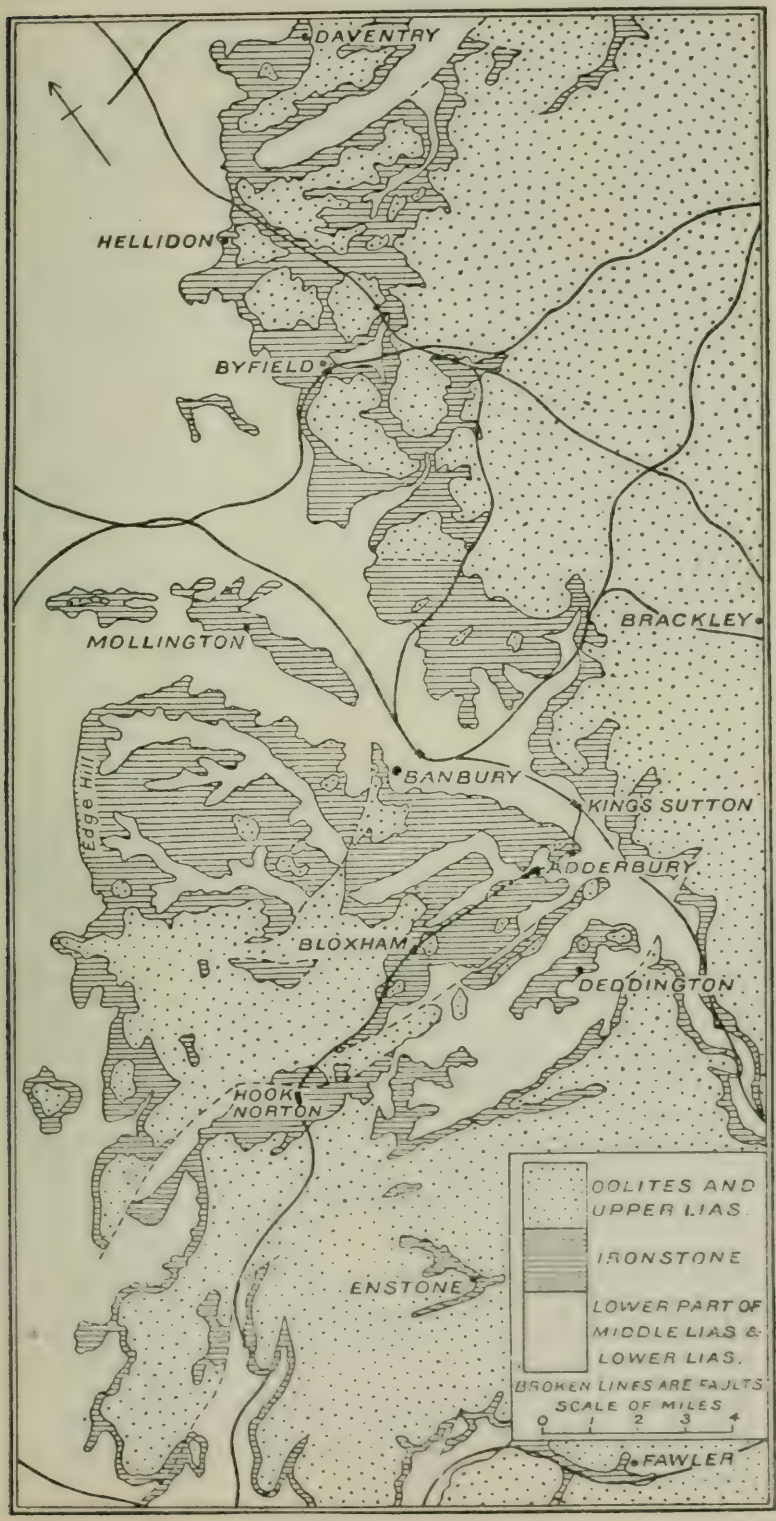
[2] 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*) 1909, pp. 74-76.

[3] A. M. Davies and J. Pringle, 'Two deep borings at Calvert Station.' *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, p. 308.

[4] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iv., 1894, p. 303.

[5] 'Water Supply of Oxfordshire' (*Mem. Geol. Surv.*), 1910, pp. 65–67.

FIG. 11.—*Sketch map of the Ferruginous Marlstone Outcrop in the Banbury District.*



absent. The underground extension of the bed, however, is of little importance as a source of iron, since the stone becomes less ferriferous under cover.

In most of the workings two well-marked series of vertical joints facilitate the removal of the rock. Frequently the joints have been widened by solution and filled with clay from above. Large 'gulls' are not common, but small faults are somewhat numerous, particularly along the Cherwell valley. The more important lines of dislocation traverse the area south-west of Banbury and along the Swere valley south of Adderbury.

The ore varies in character according to the conditions under which it occurs, as in the counties previously described (p. 109). Under a thick cover it is an oolitic rock consisting mainly of carbonates of lime and iron, with a bluish-green tint which is believed to be due to the presence of silicate of iron. Near the surface it has been more or less decalcified and converted into a soft, dark-brown rusty-looking stone. The change results in an increased percentage of the iron and silica-contents, and the ironstone becomes a siliceous ore of a highly porous character, containing up to about 20 per cent. of moisture. Between the calcareous and siliceous conditions there are intermediate stages, mainly determined by the presence or absence of Upper Lias clays in the overburden. The upper portion of the bed generally shows the change first, and the progressive alteration can be seen in the gradual appearance of cores of unaltered stone downwards. The difference of composition is shown in the following average analyses:—

Banbury and Edge Hill District.

	Top Bed. per cent.	Bottom Bed. per cent.
Iron	30·0	22·0
Silica	12·0	8·0
Lime	2·0	16·0

The richer stone, therefore, is to be looked for in such an area as a broad dip-slope which has long been exposed to weather. Ore so situated may have received further enrichment by the infiltration of iron set free in consequence of the denudation of the Upper Lias clays, which contain an appreciable amount of iron.

The average chemical composition of the ore as worked is set forth in the tables below. By comparison with the analyses given on p. 111, it will be seen that the calcareous ironstone more closely resembles the calcareous Marlstone of Leicestershire than the equivalent ore of Lincolnshire in its percentage of iron; but that it appears to be less siliceous than the stone worked in either of these counties. It is mixed with siliceous ore in about equal proportions to produce a self-fluxing ore.

Calcareous Ore.

	Average. per cent.	Range. per cent.
Iron, in stone as received	23·86	17·00 to 27·40
Iron, in dried stone	28·07	20·81 to 31·00
Silica	8·49	7·00 to 9·45
Alumina	7·80	5·29 to 9·28
Lime	16·93	11·68 to 24·07
Magnesia	0·40	0·08 to 0·64
Manganese	0·24	0·09 to 0·38
Sulphur	0·04	0·01 to 0·09
Phosphorus	0·27	0·15 to 0·36
Moisture	12·69	10·00 to 17·73

SILICEOUS ORE.

	Average.	Range.
Iron, in stone as received	30·59	30·13 to 31·20
Iron, in dried stone	38·60	37·20 to 40·00
Silica	10·29	9·89 to 10·55
Alumina	6·75	4·05 to 9·18
Lime	2·83	2·26 to 3·89
Magnesia	0·39	0·30 to 0·46
Manganese	0·29	0·20 to 0·36
Sulphur	0·06	0·03 to 0·12
Phosphorus	0·28	0·13 to 0·44
Moisture	20·00	19·00 to 22·00

The iron-content of the ore on the long dip-slope between Banbury and Edge Hill increases along the western edge of the area, and is higher, as might be expected, than on the lower slopes of the plateau nearer Banbury, where the rock-bed is still partly covered by outliers of Upper Lias clays. The range of percentages of the various constituents shown in the table below is based on the results of numerous analyses:—

ANALYSES OF RAW ORES FROM BETWEEN BANBURY AND EDGE HILL.

	Per cent.
Iron, as received	24·35 to 30·00
Silica	10·62 to 14·00
Alumina	6·00 to 8·09
Lime	9·96 to 13·20
Magnesia	traces to 1·34
Manganese	0·46 to 0·60
Sulphur	0·03 to 0·05
Phosphorus	0·22 to 0·25
Moisture	11·35 to 15·54

The stone is not worked at present, except for building purposes, but arrangements to open up the area as a source of iron-ore are well advanced. In the long outlier on which Mollington stands, the raw stone yields between 18 and 20 per cent. of iron, and is calcareous; nothing is known of the Deddington tract.

Excluding the narrow outcrop extending along the western and southern margins of the field and also the inliers around Enstone, the total area occupied by the ironstone-bed as shown on the map amounts to 34,650 acres; a part of this, computed to yield over 36,000,000 tons, is more or less developed, but whether the whole of the remainder will be found profitable to work remains to be proved. It is probable, however, that most of the ore covering the plateau is workable, and that if worked to an average depth of 12 feet over an area of 10,656 acres, with an output of 2,500 tons per foot-acre, it would yield 319,680,000 tons.

The workings are all opencast, and in several localities steam-excavators are used, filling direct into railway-trucks. The ironstone is worked under cover ranging up to 14 feet in thickness, and in view of the deterioration previously referred to, is not likely to be followed farther or mined. After the ore has been removed, the materials which formed the cover are replaced. The ore is screened in one locality only, and calcined before dispatch in three localities.

The Marlstone has been worked with varying success as an iron-ore almost continuously since the year 1859. In that year

attention was drawn by Hull[1] to its ferruginous nature near Fawler, and shortly afterwards workings were established in what became known as 'Blenheim ore.' In the following year workings were opened up at Adderbury, Kings Sutton, and temporarily at Steeple Aston. In 1864 Howell[2] pointed out that the same bed is a good ironstone from 6 to 9 feet in thickness in the neighbourhood of Swalcliffe, and "that it may possibly be found worth working when the country to the west of Banbury is more opened up by railway." This anticipation was realised when the Banbury and Cheltenham railway was completed, and workings were opened at Hook Norton. In 1914 the stone was being won only at Hook Norton, Adderbury and near Kings Sutton, but as a result of an increased demand new openings have been made at Bloxham and Sydenham, near Adderbury, and in the northern part of the area at Byfield and Charwelton, localities conveniently situated in respect to railways; whilst numerous additional working-faces on the Edge Hill plateau are in contemplation so soon as mineral-lines have been constructed.

The returns from Oxfordshire, Northamptonshire and Warwickshire are not distinguished from those of other counties in the Home Office Statistics, excepting for the years 1899 and 1900, when 166,163 and 193,222 tons were obtained. Returns of individual pits appear to have been made prior to the year 1881. At Fawler the quantity of ore raised between the years 1858 and 1866 varied from 1,200 tons (in 1858) to 5,600 tons (in 1861); no independent returns were issued after 1866, and the workings were discontinued in 1887. At Adderbury over 4,000 tons were raised in 1859 and 1860; for nine years subsequently the stone appears to have been unworked, but from 1869 to 1881 the quantity varied between 1,233 tons (in 1879) and 56,536 tons (in 1872). After 1881 the returns were included with those of Rutland. The output for the year 1917 was 434,435 tons, showing a striking increase over the figures for 1900.

Local Details, Analyses, etc., of Marlstone Ores.

Lincolnshire. By C. B. Wedd.

The most northerly workings of the Marlstone ore in Lincolnshire are those of Mr. E. P. Davis (Bennerley Furnaces) at Fulbeck. The ironstone is being worked westward from the railway east of Fulbeck, towards its outer edge. The general section in the pit-face, which has a length of 900 feet, is:—

	Ft.	Ins.
Cover.—Soil and rubble of calcareous ironstone: thickness 2 ft. 6 ins. to 5 ft. ... ... average	3	0
Ironstone.—Fissile and partly current-bedded, more or less oolitic ferriferous limestone, weathering light yellowish-brown, some of it blue-hearted: abundant *Terebratula* ... thickness	3	0
More massive, less calcareous, oolitic ironstone, of a deeper yellowish brown, when weathered, but in part blue-hearted: generally hard, but some of the lower part softer and more weathered	3	0

[1] 'Geology of the Country around Woodstock, Oxfordshire' (*Mem. Geol. Surv.*), 1859, pp. 10–12.

[2] 'Geology of the Country round Banbury, Woodstock, Bicester, and Buckingham' (*Mem. Geol. Surv.*), 1864, p. 6, footnote.

The two parts of the ironstone are sharply separated : the upper part evidently represents a limestone-bed more durable than usual in the Marlstone ore, and less absorbent of iron. The whole bed as worked maintains a thickness of about 6 feet throughout the working. The cover is removed and the ironstone got entirely by hand, the harder basal part being blasted. The ore is worked in two lifts, each of 3 feet, classified as 'limy' and 'bottom stone,' which are loaded separately and mixed afterwards according to requirements. The following analyses[1] show the general character of the ore, the first a rough analysis giving apparently the general composition of the upper and lower parts respectively, the second an analysis of the whole ironstone-bed mixed :—

	I.	II.
	per cent.	per cent.
Iron	13–30	20·0
Silica	5–10	5·5
Alumina	6–2	4·0
Lime	35–3	26·0
Phosphorus	·2	·2
Loss on calcination	—	33·0

The whole output goes to Mr. Davis's Bemerley and Erewash furnaces (Derbyshire—Notts) and is mixed with his Northampton Ironstone from Geddington (Northants). The lower part of the Fulbeck bed is calcined at the furnaces, but the upper part is used without calcination as ferric lime for fluxing.

The Yorkshire Iron Company formerly worked the Fulbeck ironstone on the east side of the railway up to the outcrop of the overlying Upper Lias clay, under which it was found that the ore soon ceased to be profitable. In this old working the general section was :—

	Ft.
Cover (Upper Lias clay)... ... ... about	9
Ironstone ... ... about	9

The upper part of the ironstone was very poor, but the lower part, oolitic, of a bluish-grey colour and earthy-looking was of rather better quality than its appearance suggests.

The same Company also worked out all the ground west of the railway between the present Fulbeck and Caythorpe pits.

Mr. Walter Burke works the Marlstone ore at Caythorpe, east of the village and chiefly on the west side of the railway, south of the station : but has recently re-opened a small pit on the east side of the railway.

Most of the ground between the railway on the east and the road from Caythorpe to Normanton on the west has already been exhausted ; but at the south end of this tract the remaining stone in the angle between the road and the railway is now being got. There the No. 1 Town-end pit is now working northward, to finish a small remnant on that side ; while a larger area remains to the southward. West of the road Mr. Burke's leases extend about half a mile southward and south-westward from Frieston village. No part of this considerable area has yet been worked, except a tract of 9—10 acres close to the railway. The small opening on the east side of the railway is being extended in a north-easterly direction. The average thickness of both cover and ore in Mr. Burke's workings is 7½ feet.

About the middle of the working-face in No. 1 Town-end pit blue sandy clay of the Middle Lias below the ironstone rises anticlinally for a few yards, so that only about 3 foot of ironstone remains above it. A short distance farther west the 'face' showed :—

	Ft.
Sandy soil... ... ... up to	4
Glacial sand with ironstone-gravel at the bottom, on an uneven surface of ironstone ... ...2 ft. to	3
Marlstone ore—	
Thin-bedded brown oolitic ironstone with few blue cores... about	6

Rhynchonella tetrahedra and *Terebratula punctata* are there abundant in the ironstone.

[1] From the Ministry of Munitions.

In the pit recently re-opened east of the railway the ironstone-bed is subdivided thus :—

	Ft.	In.
Fine small ore ... ... about	3	0
Limy bed, generally present, but variable ... ... 1 ft. 6 ins. to	0	6
Brown stone ... ... about	1	0
Blue stone at bottom ... ... about	3	0

The whole thickness is now used ; but it is stated that twelve or fifteen years ago the bottom blue bed would not have been worked.

In this pit, at a point about 310 yards south of the railway-bridge by which a road crosses the railway north of Caythorpe Station and 68 yards east of the railway a disturbance of the strata was encountered. The ironstone terminates abruptly against and is partly thrust over Upper Lias clay on the west, with a sharp but uneven junction, and it is said that the disturbance has been proved at intervals for a quarter of a mile south-westward, where it crosses the line of the railway. It is clearly due to a thrust-movement, either of deep-seated origin or possibly attributable to ice-action.

The ore is got partly by steam-navvy, partly by hand, in separate lifts. It is classified into 'limy' and 'siliceous' varieties. Analyses are as follows :—

	I.[1] (siliceous) per cent.	II.[1] (limy) per cent.	III.[2] (limy) per cent.	
Iron	28·43	91·00	27·85	
Iron (dried at 100° C.) ...	33·50	[21·96]	30·61	
Silica	17·00	8·90	7·65	
Alumina	—	5·76	3·98	
Lime	3·00	20·41	15·47	
Magnesia	—	·37	·98	
Manganese	—	·27	·33	(MnO)
Sulphur	—	·12	·249	(SO_3)
Phosphorus	—	·16	·355	
Moisture	15·15	13·50	9·00	
Loss on ignition	—	22·91	—	

The output is sold in the raw state ; it is mainly a calcareous ore, and, as such, is mixed with siliceous Northampton ore.

It is believed that practically all the workable ore has been got between Normanton and Carlton Scroop, where Mr. Burke, Mr. E. P. Davis, and the Yorkshire Iron Co., have all worked it in former years, and that in fact no good stone remains between Mr. Burke's ground south of Caythorpe and the neighbourhood of Honington.

The Stanton Ironworks Company, Ltd., have workings in the Marlstone ore at Honington and Barkston, their two quarries being separated by a shallow depression in which the width of outcrop of the ironstone is reduced to a minimum and along which the Company's railway-siding runs.

In the northern or Honington pit, working eastward with a working-face 900 feet in length, the cover varies up to 8 feet, including a little Upper Lias clay ; the ironstone averages 8 feet or 9 feet, and is fairly uniform in quality, except that it becomes more calcareous eastward under increasing cover. The ore is a yellowish-brown and blue highly calcareous oolitic ironstone, thin-bedded, with a good deal of cross-bedding. The upper half, which is thinner-bedded, is regarded as of rather better quality than the lower, in which there is a large proportion of blue cores. In fact, at the north end of the pit, the lower half consists almost entirely of blue stone.

In the Barkston pit, which, rising to slightly higher ground, is working eastward and being extended southward, with a working-face now about 900 feet in length, the thickness of ironstone averages only 5 feet or 6 feet, owing to denudation at the north end : but the full thickness, under 2—3 feet of Upper Lias clay, shows 9 feet of ore, thicker-bedded and with less cross-bedding than in the Honington pit. It is rather hard, with a certain proportion of blue cores throughout

[1] From the Ministry of Munitions.
[2] From Mr. Walter Burke.

except in the upper 2 feet. At several horizons there are bands and clusters of *Rhynchonella tetrahedra* and *Terebratula punctata*. The ore is considered rather better than that of the Honington pit.

All work is done by hand, and the whole thickness of ore is worked together. From the Barkston pit the tubs are carried by gravitation down to the railway siding : from the Honington pit they are drawn by horse-power.

An analysis[1] of the Honington—Barkston ore is appended :—

RAW ORE, AS RECEIVED.

	Per cent.
Iron	22·3
Silica	9·9
Alumina	6·2
Lime	23·0
Magnesia	·5
Manganese oxide	·55
Phosphorus pentoxide	·55
Moisture	9·9

Workable ironstone has been proved north-eastward from the Honington pit for about half a mile on both sides of the road to Ancaster.

Farther south, a small pit in Harrowby Lane[2] about two-thirds of a mile north-east of Grantham, on the main outcrop of the Marlstone east of the Witham valley, showed :—

		Ft.	Ins.
	Soil	1	10
	Rubble	1	2
	Strong rubble	1	4
[Marlstone Ore]	Rock	5	4
	Iron concretions	0	1½
	Brown marly stone	4	0
	Brown and blue clay	—	
	[ironstone]	9	5½

Two analyses made in 1892 of this ironstone gave :—

	I. (5 ft. 4 in. bed ?)	II. (Whole thickness.)
Iron	23·06	16·9
Silica	12·38	21·16
Alumina	12·32	—
Lime	15·05	—

At the north-east end of the main Leicestershire ironfield the Stanton Ironworks Company have important workings at Woolsthorpe, Denton and Harston, where their leases make practically one continuous area on both sides of the county boundary : but this area is divided on the east side northward of Denton by a valley, on the flanks of which erosion has removed the workable ore for some distance.

A large tract has been exhausted on the Lincolnshire side in the Company's Woolsthorpe lease, which has been worked continuously for 36 years : but a further considerable tract remains practically untouched on that side of the county boundary in Denton Park, south of the road from Denton to Harston.

"On the whole the workings north of the road [mainly in Lincolnshire] are in the soft thoroughly decalcified ore in which areas of poor stone are rare. With the exception of two trifling faults, having a general E.—W. course, in the S.W. part of the workings, the ironstone beds are practically undisturbed. The thickness of the ore varies between 6 feet and 10 feet. Narrow channels, filled with sand and rubble, are occasionally encountered, but these rarely cut out the entire thickness of the stone."[3]

In the Woolsthorpe tract only the Duke's pit, about three-quarters of a mile north-east of Harston, is now working within Lincolnshire. The average thickness

[1] From the Ministry of Munitions.

[2] The section and analysis are from Mr. H. Preston, F.G.S.

[3] 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 94.

of cover there, consisting of soil and disintegrated ironstone, is 3 feet 8 inches, while the ironstone, a brown well-weathered oolitic ore, averages 6 feet.

"In the workings south of the Denton road the ore is a hard compact rock, best described as a ferruginous limestone, . . . of low grade, but cheaply got and locally free from deleterious ingredients."[1]

On the west side of Denton Park west of Denton village the cover averages 4 feet and the ironstone 10 feet, with some blue beds of good quality.

The following analyses[2] represent the composition of the Marlstone ores of the Duke's pit and Denton Park:—

ORE DRIED AT 100° C.

	Duke's pit. I. Per cent.		Denton Park. II. Per cent.
Iron	35·00	...	37·00
Silica	16·80	...	12·30
Alumina	10·71	...	10·98
Lime	2·00	...	2·30
Magnesia	1·01	...	·72
Manganese oxide (MnO)	·41	...	—
Sulphur trioxide (SO_3)	·31	...	—
Phosphorus pentoxide (P_2O_5)	·89	...	·52
Moisture (in moist stone)	16·32	...	19·66

LEICESTERSHIRE: By C. B. WEDD.

On the Leicestershire side, the north-east part of the Stanton Company's Harston ground, east of that village and westward of Denton Park, has been worked out; but a considerable area of weathered ore, in part however rather calcareous, with clusters of *Rhynchonella*, remains on the north side of Harston. Under 4 feet of cover, it has a thickness of 9 feet.

East of Harston the more calcareous ore on the south side of the Denton road has for the most part been exhausted; but a large intact area of similar ore remains on the south-west side of the village.

The limy ore of Harston has the following composition[3]:—

ORE DRIED AT 100° C.

	I. Per cent.		II. Per cent.
Iron	28·2	...	25
Silica	11·4	...	10
Alumina	10·04	...	
Lime	13·2	...	15
Manganese oxide (MnO) ...	·46	...	—
Sulphur trioxide (SO_3) ...	·22	...	—
Phosphorus pentoxide (P_2O_5)	·62	...	·77
Moisture (in moist stone) ...	18·6	...	—

The cover in the Woolsthorpe and Harston workings is removed by hand; the ore is worked partly by hand and partly by steam-navvy. There is no treatment of the ore at the pits and no calcining is done there.

The small remnants of surface-ore on the high ground in Belvoir Park are regarded as too thin to be worth working.

The next workings south-westward are those of the Waltham Iron Ore Company, Ltd. (owned by the Staveley Coal and Iron Co., Ltd., and Messrs. James Oakes & Co., Ltd.), who have a large working-area extending northward and north-westward from the north end of Branston to the outer edge of the ironstone-outcrop on the top of the Marlstone escarpment.

Except on the east side, east of the road from Branston north-westward to Barkston, nearly all this area is worked out. About three-fifths of the large area

[1] Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 94.

[2] From the Ministry of Munitions.

[3] Analyses from the Ministry of Munitions.

of exhausted ground on the north-west side of Branston, as shown on the map (Pl. V), belongs to the Waltham Company, the remaining south-western part to the Holwell Company.

The Waltham Company have three pits now working :—

Name of pit.	Situation, etc.	Average thickness of ironstone. Ft. in.
(*a*) Green Lane ...	Working out a small remnant of ore on the outer edge of the outcrop, at the junction of the Waltham Co.'s ground with that of the Holwell Co.	9 0
(*b*) Long Hole	Working westward a little to north of the above, with a 'face' 2,640 feet in length, in an isolated remnant of no great extent, on the outer part of the outcrop.	5 6
(*c*) New or Bolton's ...	Working north-eastward, on the north-east side of the worked area, south and east of the intersection of the roads to Branston and Eastwell.	3 6

There is also a small area not yet worked, with an average thickness of probably less than 3 feet on the south-east side of the Eastwell road, in the middle of the worked area.

All the ground worked is in a more or less denuded tract of surface-stone. In the eastern part of the area indicated on the map as worked out, south-eastward from the Eastwell road, a considerable proportion of the ground was found to contain no workable stone, so that the average thickness of ironstone obtained on that side must have been small. It is believed that practically no more workable ore remains there, except the small patch of thin ore mentioned above, and a small area of thicker stone along the south-west side of the road to Branston.

Future working, after the exhaustion of the present pits, will proceed north-eastward, from Bolton's pit and a southward extension of it, for at least a quarter of a mile, on the north-east side of the road to Branston. There ironstone, up to 4 feet 5 inches in thickness, has been proved over a considerable area, and is locally somewhat more calcareous than elsewhere.

There is no cover of Upper Lias and practically none of boulder-clay. But in Long Hole pit, in which the three or four feet of cover consists for the most part of soil and disintegrated ironstone, some part of this contains remnants of weathered boulder-clay mixed with the soil.

The ironstone is for the most part a well-weathered brown oolitic ore, with a small proportion of blue unweathered and calcareous cores in the thicker stone of the Green Lane pit. That of the other two pits is less calcareous, softer and smaller.

The following analyses[1] represent the composition of the Waltham Company's ironstone, the ore from the three pits being evidently mixed for use before analysing :—

ORE AS RECEIVED.

	I. Per cent.	II. Per cent.	III. Per cent.
Iron	25·47	27·48	27·59
Iron (dried at 100° C.) ...	[25·38]	[37·18]	38·00
Silica	12·41	13·97	13·97
Alumina	9·30	6·94	9·45
Lime	2·04	1·50	1·36
Magnesia	·44	·75	·28
Manganese oxide	·33	·20	—
Sulphur	·12	·16	·10
Phosphorus	·29	·25	·26
Moisture	27·00	26·53	25·43
Loss on ignition	12·84	—	10·51

[1] From the Ministry of Munitions.

All work is done by hand, without blasting. Formerly the few calcareous and shelly cores were rejected, but of recent years they have been included. In the Long Hole pit, weathered and broken ironstone is saved from the cover, when practicable, but kept separate.

The Holwell Iron Company's Eaton workings adjoin the south side of the Waltham Company's, only a narrow lane (Green Lane) intervening. Their leases extend southward to Eaton and somewhat beyond.

There are four pits, of which three were working in 1917, as follows :—

Name of pit.	Situation, etc.	Average thickness of ironstone. Ft.	in.
(*a*) Duke of Rutland's	Both situated north-west of the Eastwell Road and between Green Lane on the north and the nearly parallel Eaton Road on the south; Duke's pit being the northern and Hurst's the southern half of this ground, which includes the greater portion of the Holwell Co.'s part of the exhausted area shown on the map; both pits are working westward from this exhausted area towards the outcrop	11	0
(*b*) Hurst's		12	0
(*c*) Bestall's	South-east of the Eastwell Road: working southward from the north side at the Branston Road	9	6
(*d*) Ropeway	¼ mile due south of Eaton village (not working in 1917)	—	

The average thickness of cover in these workings is 5 feet, consisting mainly of soil and weathered ironstone. The ironstone is for the most part a brown weathered oolitic ore, except in the lower part which contains blue cores, and is harder and more calcareous. During the last ten years a greater thickness of ironstone has been worked than previously, by taking some 4 feet of lower stone, which used to be left as too calcareous for use. Thus in Bestall's pit, opened somewhat recently, the Holwell Company are working 3 or 4 feet of lower stone than the Waltham Company worked years ago on the other side of the Branston road, or than they themselves worked in a large part of the Duke's and Hurst's pits. Since the ground is agricultural, it is not likely to be worked over again to recover these lower beds.

All work is done by hand. The soft less limy stone, mainly of the upper beds, is loaded separately; the intermediate or 'semi-limy' and the more thoroughly calcareous beds, which cannot readily be separated, are loaded together, all beds now being used down to the underlying sandstone. There is no farther treatment of the ore at the pits, and no calcining is done there.

The following are analyses of the Holwell Company's Eaton stone :—

	Ore as received.		Ore dried at 100° C.	
	I.[1] (siliceous) per cent.	II.[1] (limy) per cent.	III.[2] (siliceous) per cent.	IV.[2] (limy) per cent.
Iron	28·5	22·59	36·80	29·73
Silica	12·0	10·3	14·75	12·35
Alumina	—	—	11·85	8·36
Lime	2·24	10·1	3·66	12·12
Magnesia	—	—	·78	·82
Manganese	—	—	·37	·36
Sulphur	—	—	·07	·07
Phosphorus	·7	·78	·41	·36
Moisture	—	—	—	—
Loss on calcination ...	—	—	14·90	23·50

[1] From the Ministry of Munitions.
[2] From the Holwell Iron Co., Ltd.

All the Holwell Company's Eaton stone goes to their furnaces at Asfordby, near Melton Mowbray.

The Basic Ironstone Company, Ltd., are working the Marlstone ore less than half a mile south-west of Eaton, where they began operations only two or three years ago. Their pit, with a working-face 660 feet in length,[1] works northward from the north brow of the Devon valley, on the west side of the mineral railway.

The east end of the working is practically free from cover; but towards boulder-clay sets in a little farther west and increases to 22 feet at the west end. An outlier of Upper Lias clay occurs a little farther north, but there is none in the working-face, and the ironstone, regarded as a calcareous ore, is not much more calcareous under the great thickness of boulder-clay at the west end than it is at the east end. Consequently the enrichment by weathering was largely effected before the final glaciation.

The ore varies from 12 feet to 16 feet in thickness with an average of 13 feet. It is on the whole a brown more or less weathered oolitic ore, with a rather small proportion of blue cores in the lower beds; but some other beds are highly calcareous and there are frequent alternations of brown densely oolitic weathered ore with limy bands, the upper half being considered rather more calcareous than the lower. The ironstone breaks on working into fairly large blocks, with little or no rubbly ore at the top. The whole thickness is worked and mixed together,[2] no part of it being rejected. All work is done by hand: but the tougher parts of the thick boulder-clay, and some parts of the ironstone below it require blasting. No calcining is done.

The following are analyses[3] of the Basic Ironstone Company's Eaton ore:—

ORE AS RECEIVED.

	I. (siliceous) per cent.	II. (limy) per cent.
Iron	29·5	23·5
Iron (dried at 100° C.)	[36·42]	[28·66]
Silica	11·75	10·50
Alumina	9·5	6·15
Lime	2·85	10·10
Magnesia	·63	·70
Manganese	·34	·32
Sulphur	·06	·05
Phosphorus	·35	·32
Moisture	19·00	18·00

The ore is believed to maintain much the same quality north-westward throughout the area leased by the Basic Company.

The Eastwell Ironstone Company, owned jointly by the Staveley and Bestwood Companies and Messrs. James Oakes & Co., have leases extending from the north-east side of the Basic Company's ground west of Eaton, southward and eastward around the south end of the Holwell Co.'s leases and thence north-eastward as far as the west end of the Stanton Company's area. Except the small part immediately west of Eaton, all this area lies on the south-east side of the Devon Valley, and includes the village of Branston; all the ground contains calcareous ore, for the most part bordering on the outcrop of the overlying Upper Lias clay. Very little of it has as yet been worked, only about three acres having been worked out on the south-east side of the Devon Valley, and two acres west of Eaton.

The Eastwell Company's principal working-area extends from the west side of Eastwell southward and south-eastward as far as Goadby Marwood. A large tract has been exhausted west and south of Eastwell. Most of the stone is now got from the north-west end of this tract, in working northward west of the village, and from the east end, north of Goadby Marwood.

The average thickness of ironstone in the Company's Eastwell quarries is 9 feet or 10 feet, between extremes of 7 feet and 13 feet.

In the principal working-face, with a length of 1,600 feet on the west side of Eastwell there is very little cover except at the east end, near which the ore passes

[1] From the Ministry of Munitions.

[2] This seems not always to have been the practice: *see* analyses below.

[3] From the Ministry of Munitions.

under boulder clay, with Upper Lias coming in between a few yards from that end. There the thickness of cover amounts to about 15 feet, and is increasing rapidly eastward, for immediately beyond the end of the working a trial failed to reach the ironstone under 27 feet of clay. At that end and for some yards westward a belt of small step-faults running north-westward continues the line of similar step-faulting seen near White Lodge about a mile to the south-east. The faults are numerous at short intervals, with north-easterly downthrows of 1 foot —5 feet, nearly compensated by strong dips in the opposite direction, so that the level of the ironstone-bed falls gradually eastward.

For a distance of about 200 yards westward from the east end of the working at Eastwell, the ironstone is calcareous and light-coloured ; but beyond that point it changes suddenly, and becomes for the most part a thoroughly weathered brown ore, with black manganese-films on the joint-faces. The two varieties, respectively classified as 'black' and 'limy' are loaded separately, and where limy stone occurs in the lower beds in the western part of the working it is separated by hand-picking.

A similar change to calcareous stone takes place south-eastward towards Goadby Marwood, but begins at a greater distance from the outcrop of the Upper Lias, and comes on more gradually.

In the workings at the south-east end of the Company's Eastwell leases, north of Goadby Marwood, the ironstone is all calcareous, and is got beneath cover increasing to 13 feet, or somewhat more, of Upper Lias and boulder-clay. In one pit the thick cover is removed by steam-navvy ; but all other work is done by hand. No calcining is done. The following are analyses[1] of the Eastwell Company's ore :—

ORE AS RECEIVED.

	I. (Siliceous) per cent.	II. (Siliceous) per cent.	III. (Limy) per cent.
Iron	25·38	25·25	25·8
Iron (dried at 100° C.) ...	[35·59]	30·60	[29·89]
Silica	13·68	10·77	9·14
Alumina	8·69	8·57	8·37
Lime	·64	10·64	12·68
Magnesia	·77	·32	·83
Manganese (oxide)	·38	·21	Mn. ·34
Sulphur	·10	·058	·18
Phosphorus	·25	·29	·28
Moisture	28·70	17·15	13·70
Loss on ignition	14·83	17·12	18·98

The whole output goes to the furnaces of the Staveley and Bestwood Companies and Messrs. Oakes.

The Holwell Iron Company's extensive workings at Holwell, 2½ miles further south-west, as well as those of the Bennerley Iron and Coal Company on the north-west side of them, and of other companies in the neighbourhood of Holwell, have all been closed for several years. A large area was exhausted and practically no serviceable ore remains in all the ground eastward of the Stanton Company's Wartnaby workings, except that about 2 acres of thin ore is said to have been left at Holwell Mouth on the outer edge of the outcrop. The productive area, however, was intersected by the valley of the Holwell brook north-west of Holwell, and was further cut up by one or more faults in a general east-and west direction which throw out the workable stone and introduce a strip of barren ground (*see* map, Pl. V). The ironstone showed the same variations as in neighbouring tracts, "the ore being of the earthy decalcified type on the open plateau, and changing to a more calcareous type as it approaches the covering clay. . . The thickness of ore increases somewhat irregularly from its basset edge in the vicinity of the escarpment to about 14 feet, where it passes under the clay."[2] A close step-faulting in a north-westerly direction affects the ironstone in the workings on the east side of Holwell, just as at Eastwell and White Lodge[3] (*see* above).

[1] From the Ministry of Munitions.

[2] *See* 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 95.

[3] *Op. cit.*, p. 46.

The following are analyses of the Holwell ironstone :—

	I.[1] Holwell Co. (siliceous) Ore as received.	II.[2] Stanton Co. (east of Holwell) (limy). Ore dried at 100° C.
	per cent.	per cent.
Iron	32·87	—
Iron (dried at 100° C.)	40·60	25·0
Silica	10·04	12·0
Alumina	8·37	—
Lime	1·17	20·0
Magnesia	1·08	—
Manganese (protoxide) ...	·45	—
Sulphur	·03	—
Phosphoric acid	·57	·6 (Phosphorus)
Moisture	19·02	—
Loss on calcination ...	12·18	—

The Stanton Ironworks Company's Wartnaby ground comprises all the ironstone area on the south-west side of the road that runs north-west from Melton Mowbray and passes half-way between Holwell and Wartnaby. Nearly all this area is now worked out ; but four comparatively small tracts of ore remain to be got and are now being worked at the following pits :—

Name of Pit.	Situation, etc.	Average thickness of cover. Ft. In.	Average thickness of ironstone Ft. In.
No. 3 ...	On the north side of Wartnaby village, west of the road running north from the village : works southward	4 6	9 0
New Bingham	On the east side of the same road, a little farther north	4 6	(remaining ore) 7 0
No. 2 ...	Near the outer edge of the outcrop, north of New Bingham, and of the road running E.N.E. to Eastwell : a narrow remnant left between old workings north and south of it ; works southward	4 0	3 6
No. 4 ...	North of the Eastwell road, farther west : recently re-opened to work a larger remnant : works southward	thin	thin

Of the remaining patches of ironstone worked from the above pits, that of No. 2 pit is too small to show on the map (Pl. V). That of No. 3 pit is the most important : the ore there worked is a fine-grained, densely oolitic, brown stone well-weathered and decalcified, without any blue cores, all shells being dissolved : it is fairly soft, but firm and massive : joints are coated with black manganese oxide. The cover consists of soil and tough reddish loamy clay full of lumps and fragments of ironstone, with occasional irregular patches of yellow clay near the bottom, the whole being a sort of boulder-clay in which ironstone and the overlying clay are kneaded together.

In No. 2 pit the cover is practically all broken ironstone mixed with soil. The ore is similar in appearance to that of No. 3, but is probably more sandy, being merely the basal part of the ironstone, and is said to be not so good as that of No. 3.

In the other two pits the ironstone is all well-weathered brown ore without any blue cores.

All work is done by hand, the whole thickness of ironstone present being worked and mixed together, down to the underlying sandstone. Nothing is rejected, except occasional 'clay-backs' or widened joints filled with clay. Broken ore is saved from the cover by shaking out with the fork. No calcining is done.

[1] Reprinted from *op. cit.*, p. 92, and supplied originally by Mr. R. Dalgliesh, of the Holwell Iron Co.

[2] From the Ministry of Munitions.

The following are analyses[1] of the ore.

ORE DRIED AT 100° C.

	I. (Siliceous) Per cent.	II. New Bingham Pit. (Siliceous) Per cent.
Iron	33·0	38·8
Silica	14·0	16·0
Alumina	—	8·0
Lime	5·0	1·4
Magnesia	—	1·3
Manganese (oxide)	—	·49
Sulphur	—	·18 (SO_3)
Phosphorus	·5	·62 (P_2O_5)
Moisture	—	16·0

Borings for some distance westward of the worked area, where the Marlstone is overlain by boulder-clay, failed to find profitable ironstone.

The Stanton Company for the past five or six years have been getting the Marlstone ore at Tilton some miles farther south, on the east side of the village, north of the station. There the southern part of the small exhausted area was worked out some years ago by another company and the Stanton Company are working northward, on which side there is probably a considerable area of good surface-stone.

The ironstone occupies a ledge there of no great width between the escarpment of the underlying sandstone in the valley below, along which the railway runs, and the spur of a hill on the west in which the Upper Lias rises rather steeply to a capping of gravel and boulder-clay. On approaching the steeper slope the ironstone passes under a gradually increasing cover of Upper Lias clay.

The working-face, extending right across the outcrop to the foot of the hill on the west, has a length of 900 feet. The thickness of ore worked increases westward from 5 feet to about 9 feet with an average of about 7 ft. 6 in.; and the cover increases from about 2 feet of ironstone rubble and soil at the east end to 13 feet of Upper Lias clay at the west end with perhaps a remnant of boulder-clay.

At the top of the ironstone, where the full thickness is present, there is a 6-inch bed of creamy white calcareous and ferriferous oolitic limestone. The ironstone is a fine-grained oolite with much calcareous blue stone under the Upper Lias at the west end, but for the most part brown and well-weathered near the east end. All work is done by hand, with some blasting at the west end, where the stone is stronger. The whole thickness is worked together and all is loaded together, calcareous and siliceous stone alike. There is no treatment of the ore at the pit, and no calcining is done.

The following are analyses[1] of the Tilton ironstone :—

	Limy Ore. (as received). I. per cent.	Mixed Ore (dried at 100° C) II. per cent.
Iron	23·0	30·0
Silica	13·0	15·6
Alumina	—	10·8
Lime	17·0	9·7
Magnesia	—	·51
Manganese (oxide)	—	·41
Sulphur (trioxide)	—	·37
Phosphorus	1·0	1·01 (P_2O_5)
Moisture	—	16·77

[1] From the Ministry of Munitions.

Northamptonshire : By J. Pringle.

Parkgate Iron and Steel Co., Rotherham.

Open workings on north side of Charwell House 1,800 yards N.W. of Charwelton station (G.C.R.).

One-inch New Series Ordnance map, Sheet 201 ; Old Series Geological Shee 53 ; six-inch map, Northants 49 N.E.

Latitude 52° 12′ 30″ ; Longitude 1° 14′ 30″.

This property is in course of development. In May, 1917, the ore was won from a small working face which showed yellowish-brown oolitic ironstone with long narrow bluish-green cores, crowded with crinoidal fragments, 4 to 6 ins. thick, underlain by 1 ft. of brown sandy clay with numerous flattened nodules (not worked).

The ironstone varies in thickness from 3 to 8 ft. in the property owned by this company. The estimated workable area which includes ground passing under cover up to 25 feet contains between 3,000,000 and 4,000,000 tons. The following is an analysis of the raw stone :—

	Per cent.
Iron as received	24·10
Iron (dried)	28·47
Silica	8·68
Alumina	6·70
Lime	15·36
Manganese oxide	Nil.
Sulphur	·013
Phosphorus	·341
Moisture	15·36
Loss on ignition	18·50

The stone is loaded direct by steam-navvy into trucks conveyed over a branch line to the Great Central line at Charwelton and thence to Rotherham.

Northamptonshire Ironstone Co., Byfield.

Opencast workings on N. side of Stratford-upon-Avon and Midland Junction railway, ½ mile W.N.W. of Byfield station.

One-inch New Series Ordnance map, Sheet 201 ; Old Series Geological, Sheet 53 ; six-inch map Northants 49 S.E.

Latitude 52° 10′ 18″ ; Longitude 1° 15′ 2″.

This working-face was opened in May, 1915, and at that time showed :—

		Ft.	in.
Upper Lias ...	Brownish-weathering bluish grey clay with a whitish clayey limestone (Fish Bed) at base	2	3
	Sandy oolitic marl passing upwards into a reddish clay. *Tiltoniceras acutum* (Tate) abundant	0	3
Middle Lias (Marlstone Rock-bed)	Brownish-weathering oolitic ironstone with long narrow bluish-green cores frequently crowded with *Rhynchonella tetrahedra* (J. Sow.) ... ... about	10	0

The beds dip in a south-easterly direction at a low angle, and are traversed by two sets of vertical joints. An inch or so of the Upper Lias, which is firmly welded on to the top of the ironstone, is removed with it and used. The area of the workings is limited on the south and east by railway and village. Northwards the cover disappears, and the ironstone becomes decalcified, but it retains its calcareous character over the northern part of the Company's property, where it is now being opened up. An analysis shows the following constituents :—

	Per cent.
Iron in ore as received	25·9
Iron in ore dried at 100° C.	29·2
Silica	7·82
Lime	15·38
Moisture	11·08

The stone is worked by steam-navvy, loaded direct into trucks and dispatched by Stratford-upon-Avon and Midland Junction Railway.

NORTHAMPTONSHIRE IRONSTONE CO., BYFIELD.

Openwork $\frac{3}{8}$ of a mile N.W. of Byfield Station.

One-inch New Series Ordnance map, Sheet 201; Old Series Geological, Sheet 53; six-inch map, Northants 49.

Latitude 52° 10′ 25″. Longitude 1° 15′ 14″.

This pit was opened in May 1915, and in August, 1917, it showed 6 to 8 ft. of soft brown oolitic ironstone.

The rock is considerably decalcified and thus has become a siliceous ore.

An analysis, provided by the Ministry of Munitions, shows the following constituents of the raw stone:—

	Per cent.
Iron	30·45
Silica	10·55
Lime	2·26
Alumina	4·05
Magnesia	·46
Manganese	·36
Phosphorus	·44
Sulphur	·12
Moisture	19·00
Loss on calcination	15·14

The stone is removed by steam-navvy; trucks are loaded alongside the working-face, and dispatched over a siding to Stratford-upon-Avon railway to destination.

ALFRED HICKMAN, LTD., KINGS SUTTON, NEAR BANBURY.

Astrop openworks on E. side of Buston Farm, 1¼ miles N.E. of Kings Sutton station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Northants 62 N.E.

Latitude 52° 2′ 35″. Longitude 1° 15′ 40″.

The following details of one of several working-faces in the neighbourhood of Buston Farm may be regarded as typical:—

		Ft.	In.
Upper Lias	Blue grey clays with two thin bands of clayey limestones ... ...2 to	11	0
	Pale creamy oolitic marl passing upwards into a soft reddish-brown clay with seams of dark brown iron-oxide ...	0	4½
Middle Lias (Marlstone Rock-bed).	Strong brown-weathering, bluish-green oolitic ironstone with numerous pebble-like concretions in lower 2 feet ...	8	0

The beds are well-jointed, and dip towards the S.S.E. at a low angle. The ironstone contains large green cores which are here and there interlaced with thin seams of dark brown iron-oxide. The basal layer of the Upper Lias is firmly welded on the upper surface of the Rock Bed and used with it. The ironstone yields about 23 per cent. of iron, 7 per cent. of silica, and 20 per cent. of lime. The reserves of the present workings extend to about 30 acres.

The stone is quarried by hand, and carried to calcining kilns (Gyers) which are situated alongside the G. W. main line. After calcination the ore is sent by rail to Bilston, Staffs.

OXFORDSHIRE: By J. PRINGLE.

ALFRED HICKMAN, LTD., KINGS SUTTON, NEAR BANBURY.

Sydenham pit (openwork), 500 yards south-west of Kings Sutton station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 10 S.W.

Latitude 52° 0′ 52″. Longitude 1° 17′ 5″.

This property was opened in March, 1914, and is being rapidly developed. The pit in August, 1917, showed 2 to 3 ft. of Upper Lias resting on 5 to 9 ft. of oolitic ironstone, well-jointed and containing concretions at its base.

The dip is scarcely measurable, except near a small fault. Close to the fault there is a 'gull,' 25 to 30 ft. in breadth, which is filled with a broken mass of soft micaceous sandstone. The property extends to nearly 300 acres. The ironstone is worked as a calcareous ore, but is locally siliceous, particularly towards the eastern end of the workings. The raw stone contains about 22 per cent. of Iron, 8 per cent. of Silica, 18 to 24 per cent. of Lime, 5 per cent. of Alumina, ·40 per cent. of Phosphorus, and 10 per cent. of Moisture.

The rock is quarried by hand and conveyed to calcining furnaces which adjoin the G. W. railway (Banbury-Cheltenham branch). After calcination, the ore is dispatched to the Company's furnaces at Bilston.

COCHRANE & CO., WOODSIDE, LTD., OXFORD ROAD, ADDERBURY.

New College pit (openwork) slightly over ½ mile S.W. of Adderbury station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 10, S.W.

Latitude 52° 0′ 15″. Longitude 1° 19′ 10″.

The pit is about 300 yards in length, and shows 3 ft. of Upper Lias resting on about 12 ft. of hard oolitic iron-ore with concretions at the base.

The ironstone is approximately horizontal, and is traversed by numerous wide vertical joints which are filled with clay washed down from the Upper Lias. The iron-ore is not uniform in the lower beds, the distribution of the small oolitic grains of iron-oxide being irregular. It is a calcareous ore, and is practically self-fluxing. The following analysis of the raw stone from this pit is given by Dr. Hatch.[1]

	Per cent.
Fe as received	27·13
Fe dried at 212° F.	30·90
SiO_2	9·27
Al_2O_3	5·29
CaO	11·68
MgO	·08
Mn	·09
S	·09
P	·27
Other constituents	1·59
Moisture	12·20
O	12·16
Difference	20·15

The raw stone is carried by horse-trams to parting, thence by cable to a siding adjoining G. W. line for dispatch to Dudley (about 54 miles). The reserves are ample.

COCHRANE & CO., WOODSIDE, LTD., OXFORD ROAD, ADDERBURY.

Berryhill pit (open work), 500 yards W.S.W. of Adderbury station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 10 S.W.

Latitude, 52° 1′ 30″; Longitude, 1° 18′ 50″.

This section exhibits a soft well-bedded, yellowish-brown oolitic ironstone, 6 ft. thick, but with base nowhere exposed to view. The ore is well-jointed and more completely decalcified than that of the New College pit; the majority of the fossils occur in the form of brown earthy casts. The most recent analysis[2] is as follows:—

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[1] 'The Jurassic Ironstones of the United Kingdom—economically considered.' *Journ. Iron and Steel Inst.*, vol. xcvii, 1918, p. 94.

[2] *Ut supra.*

	Per cent.
Fe as received	30·13
Fe dried at 212° F.	37·20
SiO_2	9·89
Al_2O_3	7·04
CaO	3·89
MgO	0·30
Mn	0·20
S	0·03
P	0·27
Other constituents	1·30
Moisture	19·00
O	13·58
Difference	14·37
	100·00

The stone is quarried by hand and carried in tubs to siding adjoining G.W. line for despatch to Dudley (about 54 miles).

COCHRANE & CO., WOODSIDE, LTD., OXFORD ROAD, ADDERBURY.

Open work in field, five furlongs south-west of Adderbury Station.

One-inch Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map. Oxford 10 S.W.

Latitude, 52° 0 3″; Longitude, 1° 18′ 45″.

The pit shows, under 4 feet of brown soil, soft oolitic ironstone 7 ft. thick. The distribution of the iron is fairly uniform. The ore is decalcified, and traversed by numerous vertical joints. The working-face of the pit is about 200 yards in length, and there is a reserve of between 8 and 9 acres in this property.

The following analysis of Adderbury ironstone is given by Wilson.[1] The locality is not defined and the analysis does not appear to represent the character of the ore of the pit described above:—

	Per cent.
Iron peroxide	30·20
Iron protoxide	3·40
Alumina	9·10
Lime	14·80
Magnesia	·70
Insoluble siliceous matter	12·20
Phosphoric acid	·70
Carbonic acid	13·30
Water	15·60
	100·00
Metallic iron	23·7

BLOXHAM IRONSTONE CO., 115, COLMORE ROW, BIRMINGHAM.

Openwork, near Old Barn Farm, slightly over 1 mile E.N.E. of Bloxham Church, and ½ mile N.W. of Milton Halt (G.W.R.).

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 9 N.E.

Latitude 52° 1′ 0″. Longitude 1° 20′ 52″.

This property was opened up in May, 1918. A long working-face extending across the property showed 2 or 3 ft. of Upper Lias, resting on 12 to 14 ft. of oolitic iron-ore with large green cores and a layer of flattened nodules at base. This is a 'limy' ore containing from 16 to 22 per cent. of iron, about 8 per cent. of silica, and 22 per cent. of lime. The workings are connected by a siding to the Great Western line (Banbury and Cheltenham branch), and ore is loaded directly into trucks by steam-navvies for dispatch to South Wales.

BRYMBO STEEL CO., BRYMBO, NEAR WREXHAM.

Redlands quarry, about ½ mile N. of Hook Norton station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 9 S.W.

Latitude 52° 0′ 5″. Longitude 1° 28′ 15″.

[1] E. Wilson. 'The Lias Marlstone of Leicestershire.' *Midland Naturalist*, vol. viii, 1885, p. 154.

The northernmost of several working-faces on this property showed, under a few feet of rubble, oolitic ironstone with large green cores near the base, 12 ft. thick, and below this brown-weathering shales with concretions.

The beds dip N.N.E. at a low angle and are traversed by two sets of vertical joints. The workings are limited on the eastern side by a fault which trends N.W. to S.E. and throws in Upper Lias clays. The ironstone is calcareous and contains well preserved specimens of *Rhynchonella tetrahedra* (J. Sow.) and *Terebratula punctata* J. Sow. The green cores at the base are usually surrounded by a crust of dark brown concretionary iron, and are often interlaced with 'strings' of a similar substance. The iron in the raw stone ranges between 25 and 28 per cent.; silica between 9 to 14 per cent.; and lime between 10 to 16 per cent. The following is an analysis published recently by Dr. Hatch.[1]

	Per cent.
Fe as received	27·40
Fe, dried	31·00
SiO_2	8·84
Al_2O_3	9·28
CaO	12·37
MgO	·64
Mn	·38
S	·06
P	·15
Moisture	11·60
O	11·90
Loss on ignition	17·15

The stone is quarried by hand and conveyed to kilns where it is mixed with the siliceous stone from Park Farm and calcined. After calcination it is sent by G.W. railway to the Brymbo Steel Works, near Wrexham, and the Earl of Dudley Co., Round Oak, Staffordshire.

BRYMBO STEEL CO., BRYMBO, NEAR WREXHAM.

Park Farm open workings, 250 yards E. of Hook Norton Station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 9 S.W.

Latitude 51° 59′ 35″. Longitude, 1° 28′ 15″.

This property has been recently opened, and has a working-face about 60 chains in length, showing, under 3 feet of disintegrated ironstone, oolitic ironstone with occasional green cores in the lower part, 8 feet thick, and below this brown shale with many concretions (not worked) 2 feet thick.

The rock is much decalcified and the green cores are narrow and inconspicuous they are usually surrounded by layers of dark brown concretionary iron. The raw stone contains between 26 and 31 per cent. of iron; the following is an analysis of the ore published by Dr. Hatch.[2]

	Per cent.
Fe, as received	31·20
Fe, dried	40·00
SiO_2	10·45
Al_2O_3	9·18
CaO	2·34
MgO	0·33
Mn	0·33
S	0·04
P	0·13
Moisture	22·00
O	13·65
Loss on ignition	10·21

The raw stone, which includes nearly the whole of the disintegrated rock of the cover, is worked by a steam-navvy, and screened. It is conveyed to calcining kilns which are situated alongside the G. W. line (Banbury—Cheltenham branch), and mixed in equal proportions with the raw stone from the Redlands quarry before calcination. The calcined ore is dispatched to the Brymbo Steel Works near Wrexham, and to the Earl of Dudley Co., Round Oak, Staffordshire.

[1] 'The Jurassic Ironstones of the United Kingdom—economically considered.' *Journ. Iron and Steel Institute*, 1918, p. 94.

[2] *Ibid.*

H. W. Baker & Sons, East End, Hook Norton.

Shallow pit, 250 yards N. of Hook Norton station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 9 S.W.

Latitude, 51° 59′ 45″. Longitude, 1° 28′ 20″.

The working face shows a soft brown oolitic ironstone to the depth of 9 feet under brown soil varying in thickness from 2 to 4 feet, the section being similar to that of the Park Farm workings about 400 yards to the south-east. The reserves are small, and the pit will soon be worked-out.

The stone is carted to Hook Norton station and sent by rail to the Lilleshall Co., Ltd., Oakengates (about 66 miles).

H. W. Baker & Sons, East End, Hook Norton.

Openwork on east side of road between Hook Norton and Sibford Ferris, $\frac{5}{8}$ of a mile N.W. of Hook Norton station.

One-inch New Series Ordnance map, Sheet 218; Old Series Geological, Sheet 45; six-inch map, Oxford 9 S.W.

Latitude, 52° 0′ 2″. Longitude, 1° 28′ 52″.

The section resembles that of the Redlands Quarry (*see* p. 138), except for the presence of a small patch of Upper Lias clay at the western end of the pit. The ironstone is about 12 feet thick, and contains in the bottom layers the usual dark-skinned pebble-like concretions. Green cores with well preserved fossils are present at the base, but they are usually narrow and inconspicuous.

The ironstone is quarried by hand and carted to the station (about 1 mile) for dispatch to the Lilleshall Co., Hollinswood, and the Earl of Dudley's furnaces at Round Oak. The average weekly output is about 300 tons. The property unworked measures 60 acres, but reserves for future use may be found in the neighbourhood.

Warwickshire. By J. Pringle.

Burton Hills, 2 miles W.S.W. of Fenny Compton station.

One-inch New Series Ordnance map, Sheet 201; Old Series Geological, Sheet 53; six-inch map, Warwick 46 S.W.

Latitude, 52° 9′ 42″. Longitude, 1° 25′ 15″.

Some disused workings near the windmill were formerly worked by the Willingsworth Ironstone Co. The following particulars of a section east of the windmill may be regarded as typical of the Rock Bed of this area :—

		Ft.	in.
Upper Lias	Shales with thin clayey limestones, 1 to	8	0
Middle Lias	Thick-bedded brown-weathering sandy oolitic ironstone with large green cores, numerous dark-skinned pebble-like concretions at base ... ... about	15	0
	Brown shales with nodules ... seen	4	0

The dip is S.E. at 5°. The area is traversed by several east-to-west faults which introduce narrow belts of Upper Lias clays. The workings have been abandoned for several years; but during the period of activity the raw stone was carried by an overhead transport to a siding adjoining the Stratford-upon-Avon and Midland Junction railway at a point nearly midway between Kineton and Fenny Compton stations. The ironstone is calcareous, and an analysis, for which we are indebted to Mr. A. A. Dolan, of a sample obtained at a spot S. of the windmill shows the following constituents :—

	Per cent.
Iron	25·0
Silica	8·0
Lime	24·0
Mn	·2
P	·15

Arrangements are being made to restart work at this locality.

CHAPTER VI.

NORTHAMPTON (INFERIOR OOLITE) IRONSTONE OF MID AND SOUTH LINCOLNSHIRE, RUTLAND AND NORTHAMPTONSHIRE.

By C. B. Wedd.

Stratigraphical Description.

Before describing the Northampton Ironstone, it is well to consider the changes in the overlying strata as affecting the limestones quarried in working the ironstone and used for fluxing it. The following table gives the sequence of these strata and of the ironstone-beds, with their range of thickness in Lincolnshire and Northamptonshire[1]:—

	Range of Thickness in Feet.		
	Lincolnshire.		Northamptonshire.
Lower Oolites.			
Great Oolite Series:—			
Cornbrash:—hard blue fossiliferous limestone	3½—8		5—15
Forest Marble Series and Great Oolite Clay:—variegated clays with layers of calcareous and ferriferous nodules ...	13—26		3½—14½
Great Oolite Limestone:—hard shelly more or less oolitic limestones in courses, with marly partings and oyster-beds	2½—36½		7—25½
Upper Estuarine Series:—variegated clays with shell-beds, ferruginous at the base	10½—40	Variable: usually:—(iii.) Clay with rootlets. (ii.) Estuarine limestone (1 ft. to 5 or 6 ft.). (i.) Clay of various colours: an oyster-bed.	7—38½
Inferior Oolite Series:—			
Lincolnshire Limestone:—pale oolitic limestones (freestones) and hard shelly limestones...	132—36½		77—0
Collyweston Slate:—fissile sandy limestone and sand...	0—5		10—0
Lower Estuarine Series:—pale sands and laminated clays...	0—34		15—0
Northampton Sand:—Northampton Ironstone[3] (oolitic) and lower sandstone ...	0—26	Variable Beds[2] (Northampton district):—calcareous and fissile or soft sandstones. Northampton Ironstone[3] (oolitic) and lower sandstone ...	0—30 / 30—0
Lias.			
Upper Lias:—blue clays ...	—		—

[1] The sequence and thicknesses of strata are based on the following works:—'Geology of Rutland' (*Mem. Geol. Surv.*), 1875; 'Geology of Lincoln,' *ibid.*, 1888; 'Jurassic Rocks of Britain,' *ibid.*, vol. iv., 1894; 'Thicknesses of Strata,' *ibid.*, 1916; Beeby Thompson, 'Geology of Northamptonshire and Parts of Rutland and Warwickshire'; *Geol. Assoc.*—'Geology in the Field: the Jubilee Volume of the Association,' 1910.

[2] B. Thompson, *op. cit.*, pp. 468, 471.

[3] In this account the term 'Northampton Ironstone' is applied to this ore alone and is used irrespectively of the source of the ore.

Discordance of bedding and local erosion at the junction of the Lower and Upper Estuarine Series have suggested some degree of unconformability. In fact Prof. Judd regarded the Upper Estuarine Series as always slightly unconformable to its underlying beds.[1]

The Northampton Ironstone usually forms the upper part of the Northampton Sand as here defined; for the 'Variable Beds' are confined to the immediate neighbourhood of Northampton, where they are regarded by Mr. Thompson as 'an addition to the normal sequence due directly and indirectly to coral growth within the area, that is to the actual addition of calcareous matter, and to the arrest of sediment of other kinds by the reefs.'' As in that neighbourhood the sandy basal development of the Northampton group becomes thin or disappears, the ironstone there alone belongs to the lower part of the group.

The Lincolnshire Limestone, reaching its maximum development in Lincolnshire, where in places it lies immediately or almost immediately above the ironstone in the absence or feeble representation of the Lower Estuarine Series, thence thins and disappears southward along a line running south-westward by Kettering. Consequently the Upper and Lower Estuarine Series come together, and where these two similar series diminish, the Great Oolite Limestone, more sandy and less valuable as a flux, comes to occupy much the same position above the ironstone as the purer Lincolnshire Limestone occupies farther north (*see* Pl. VII, Sects. 1 and 2). The two limestones are often similar in appearance, though differing in age and in fossil-contents.

The Collyweston Slate disappears as such southward. But in the Deene Pit near Corby (Northants) it is represented by large bullions, retaining all the fissility of the 'slate,' but set in a matrix similar to the Estuarine beds, and consequently it adds to the thickness of sandy and clayey strata above the ironstone and increases it locally to 20 feet or more.

Description of the Ore-bed.

The ironstone-bed itself usually retains the same general character from top to bottom. In its unweathered state it consists of green, more or less densely oolitic carbonate-ironstone, variably sandy and calcareous, but rarely in any part so highly calcareous as the unweathered Marlstone ore (which otherwise it resembles closely in appearance and colour), and on the whole more sandy, especially towards its base.[2] It weathers to a brown or yellowish-brown limonite ore, in which the oolitic structure is sometimes more or less completely obliterated. The Northampton ore usually shows a slightly more yellowish tint than the Marlstone ore, after exposure to weather. Though sometimes more massive, it often has a thin-bedded structure, but is generally free from shaly partings.

Not infrequently (*e.g.*, in the Islip Company's Woodfield Mine) a bed of hard dense and homogeneous green or grey ferrous-carbonate stone devoid of oolitic structure, appears locally in the

[1] 'Geology of Rutland' (*Mem. Geol. Surv.*), 1875, p. 90.

[2] For suggestions as to the origin of such ores, *see* above, p. 13.

Iron Ores, Vol. XII, to face p. 142.

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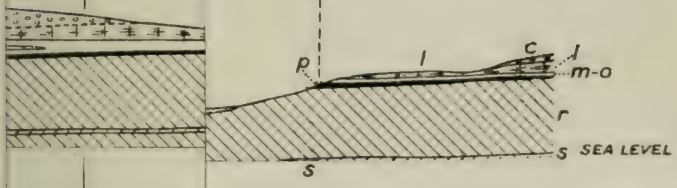
County boundary

Railway

INTERSECTION WITH SECT. 2

IRONSTONE DIMINISHES TO S.E.

N.



AMPTON IRO

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NE
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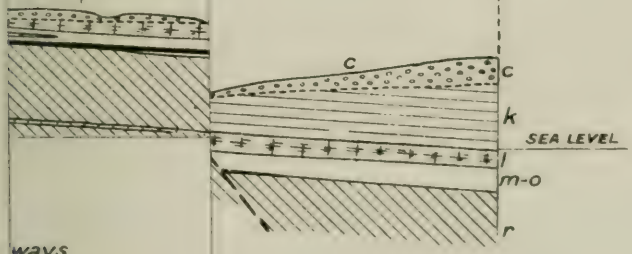
IRONSTONE DIES OUT TO EAST

BOREHOLE



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vith

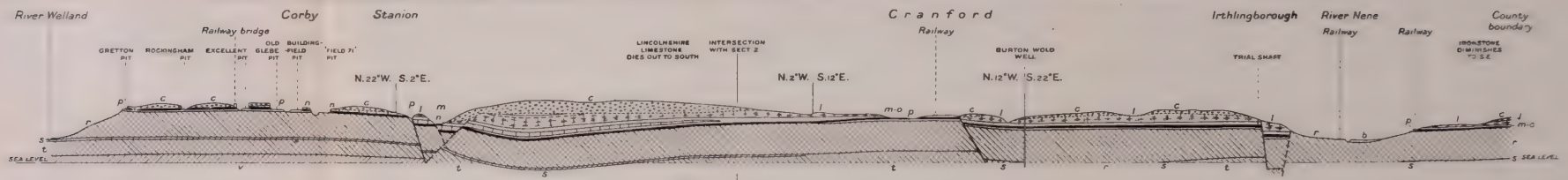
Ironstone shewn
lines.

HORIZONTA

2

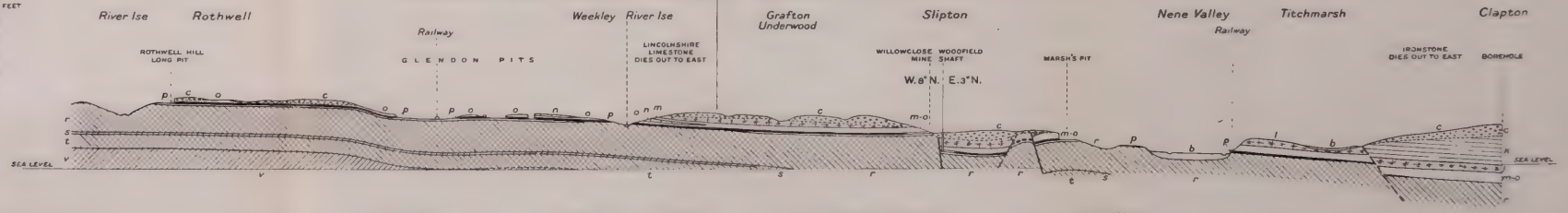
PLATE VII

SECTION 1.– CROSSING OBLIQUELY THE MAIN NORTHAMPTON IRONSTONE FIELD, FROM THE PITS NORTH OF CORBY TO THE COUNTY BOUNDARY BEYOND IRTHLINGBOROUGH.



SECTION 2.– ACROSS THE MAIN NORTHAMPTON IRONSTONE FIELD, FROM ROTHWELL TO CLAPTON.

VERTICAL SCALE
500 FEET
400
300
200
100
0



b Alluvium & Gravel } Recent	k Oxford Clay with Kellaways Beds at base	m Upper Estuarine Series	r Upper Lias	Northampton Ironstone shewn by thick black lines.
c Drift ... Glacial	l Great Oolite Series with Cornbrash at top	n Lincolnshire Limestone } Inferior Oolite Series	s Marlstone rock-bed } Middle Lias	
		o Lower Estuarine Series } Inferior Oolite Series	t Clays	
		p Northampton Ironstone and Sand } Inferior Oolite Series	v. Lower Lias	

HORIZONTAL SCALE
0 1 2 3 4 5 6 MILES

ironstone. Elsewhere such a bed may be represented by a band of similar nodules, as at Finedon. Rarely, a part of the ironstone passes locally into a ferriferous limestone, as, for a short distance, in the Sheepbridge Company's Desborough quarry. More frequently some part of it becomes more sandy than the rest, and may have to be rejected. Such sandy beds usually extend downward from the top or upward from the bottom, but are seldom found in the middle of the ironstone: in one of the workings near Finedon the upper 7 feet or 8 feet of a total thickness of 15 feet becomes sandy for some distance and unfit for use.

In the shallow mines or the deepest open workings, the ore usually retains in the main, but not completely, its unweathered state as a green carbonate-stone. Under such conditions oxidation is found to have taken place along joints and certain bedding-planes, and generally to have pervaded the mass as a minute brown speckling. In the shallower open workings more extensive oxidation has affected the upper beds most and has proceeded irregularly downward with diminishing alternation of brown with green beds. In some of the surface-workings free from cover the whole thickness, or what remains of it, is completely oxidized throughout.

One peculiar characteristic of the weathering Northampton ore serves at once to distinguish it from the Marlstone ore. The solution and redistribution of iron results in the formation of vertical and horizontal crusts of rich dark brown structureless limonite along joint- and bedding-planes, which thus break up the stone into rectangular blocks, or 'boxes,' diminishing in size and increasing in number, by similar infiltration along more numerous planes, as weathering proceeds. The final stage of this process exhibits a close cellular structure in which small rectangular cells of dark brown limonite enclose a central core, usually pale in colour through exhaustion of iron.[1] No similar structure develops to any marked extent in the weathered Marlstone ore, in which, however, an interstitial deposit of ferric oxide tends to bind the oxidized ooliths together.

The general absence of beds crowded with *Rhynchonella* and *Terebratula* serves farther to distinguish the Northampton ore, for it is almost barren of fossils for long distances, though locally highly fossiliferous.[2]

The ironstone, as a rule, passes down rather suddenly into a green ferriferous sandstone several feet in thickness, but variable. This, generally including at the bottom a sparse bed of phosphatic nodules, constitutes the actual base of the Inferior Oolite and rests upon the Upper Lias clay.

The downward change of the ironstone into sandstone, though often rather sudden, is not usually abrupt. Consequently in the absence of a sharp plane of demarcation the ironstone is worked a little lower down in some workings than in others, with the result that its silica-average rises.

[1] For a full description of this structure, *see* 'Geology of Rutland' (*Mem. Geol. Surv.*) 1875, pp. 118, 120, 123.

[2] *See* Thompson, *op. cit.*, p. 469.

Towards the south-western extremity of the ironfield, before the ironstone itself is affected by any siliceous degeneration, a change takes place in its relative position. A bed of ferriferous sandstone, usually green when unweathered, but varying within short distances between a firm green sandstone and a soft buff or brown sand like the overlying Estuarine sand, comes in at the top of the ironstone and attains a thickness of 20 feet or more. This is a sandy phase of the 'Variable Beds' of the Northampton district (*see* above, p. 142). The intercalated sandstone above the ironstone, even where it has the same green colour as the ironstone below, is readily distinguishable from it at a distance; for the rubbly appearance imparted to the ironstone by the characteristic 'box' or cellular structure (described above) does not extend upward into the sandstone, which has the aspect of a massive bedded rock.

Its marine origin connects the sandstone rather with the ironstone-group than with the Estuarine beds above. Consequently, in the absence of the sandy base of that group (for the green sandstone below the ironstone becomes thin or disappears locally in the same neighbourhood), the intercalated green sandstone above has the effect of transferring the ironstone from the top to the bottom of the group.

This sandy development at the top of the ironstone is conspicuous in all workings from Duston southward to Towcester, but is not found at Earl's Barton and Whiston, the nearest workings on the east.

The marine Northampton Sand, in the sense in which the term is used here (*see* table, p. 141), represents in an attenuated form several ammonite-zones combined, but elsewhere distinct—viz., those of Jurensis (upper part), Torulosus, Opalinus, and Murchisonæ (lower part). Characteristic fossils are the ammonites *Lytoceras wrighti*, S. Buckman; *L. opalinum* (Rein); *Ludwigia murchisonæ* (J. de C. Sow.); the lamellibranchs *Astarte elegans*, Sow.; *Ceromya bajociana*, d'Orb; *Hinnites velatus* (Goldf.); *Pecten personatus*, Goldf.; and several species of *Trigonia;* also brachiopods of the groups of *Rhynchonella cynocephala*, Rich.; *Terebratula fimbria*, Sow., and *T. submaxillata*, Sow.[1]

Range and Thickness.

The Northampton Ironstone, from its most northerly development in Lincolnshire southward to Grantham, passes rapidly under the thick Lincolnshire Limestone and nowhere presents broad areas of surface-stone. This arises partly from the thinness of the over-lying Lower Estuarine Series, so that the hard ironstone and the thick, resistent limestone crop out close together in one escarpment capped by the latter (*see* map, Pl. V. and Hor. Sect. Pl. VI, Sect. 1), and partly from the less variable inclination of the strata (cp. Pls. VI and VII).

South of Grantham the outcrops begin to widen and spread out into broad plateaux, usually capped by extensive outliers of the limestone, and intersected or detached by numerous valleys.

[1] For the zones and lists of fossils, *see* 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iv. 1894, p. 167, and B. Thompson, *op. cit.*, p. 470.

These conditions become farther accentuated southward throughout Rutland and the main ironfield of Northamptonshire (*see* below, p. 149 and Maps, Pls. V and VIII), where the diminishing Lincolnshire Limestone finally gives place to the Great Oolite Limestone as the capping of the plateaux above the combined Upper and Lower Estuarine Series (*see* Hor. Sects., Pl. VII, Sects. 1 and 2).

Beyond the main ironfield the strike changes from south to south-west, and the outcrop narrows with some increase of south-easterly dip.

The Northampton Ironstone, as a whole, does not vary rapidly in thickness from place to place. In Northamptonshire the full thickness of ironstone, *i.e.*, the complete thickness where the upper part has not been removed by denudation, ranges from about 6 feet to 15 feet, with an average of probably about 10 feet. It is said that an exceptional thickness of 25 feet was worked at Duston,[1] but no evidence remains on the ground to confirm this. South-west of Little Addington also the ore is believed to be exceptionally thick. The average thickness of stone worked is about 8 feet in Northamptonshire, the difference being due to the extensive working of partially denuded stone and to the rejection of inferior parts. In Rutland and Lincolnshire, respectively, the average worked is about 8 feet 6 inches and 8 feet, the full thickness being 10 feet or 11 feet in Rutland and ranging up to 12 feet or more in Lincolnshire.

Faults are not numerous and do not as a rule interfere to any extent with the working of the iron-ore. Of the tracts so far known to contain them, the belt of ground extending southward from Sudborough west of the Islip furnaces is probably the most seriously affected, being faulted in both longitudinal and latitudinal directions. In other cases faulting may have had an effect of practical importance upon the depth of the ironstone, viz., between Colsterworth and Buckminster (South Lincs.), between Cranford and Burton Latimer, and south-west of Irthlingborough (Northants).

At Wakerley and elsewhere in the neighbourhood the ironstone is closely step-faulted with numerous small south-easterly downthrows, rather more than compensated by intervening sharp north-westerly dips.[2] The phenomenon, however, scarcely has any detrimental effect on the working of the ironstone, except where it introduces 'sand-gulls.'

Of more consequence in working are the sand- or clay-gulls frequently encountered in the ironstone. These are of two kinds, not generally distinguished:—

(i.) Pockets of sand or clay let down into the ironstone often through solution, along joints, less frequently by faults; or introduced into erosion-cavities.

(ii.) Small and sharp anticlinal folds abruptly pinching up the sandy base of the ironstone and bringing it up in places to the top of the working, with total loss of the ore.

[1] Thompson, *l.c. cit.*: W. H. Hudleston, *Proc. Geol. Assoc.* vol. iv, 1874, p. 127.

[2] The same phenomenon is seen in the Marlstone ore of Leicestershire: *see* 'Geology of Melton Mowbray' (*Mem. Geol. Surv.*), 1909, p. 46, and above, p. 132. It may probably be the result of movement in a relatively thin, hard and brittle bed intercalated between softer and more plastic strata.

Analyses of Northampton Ironstone.

Raw Ore, 'as received.'	Average Values of the several Chief Chemical Constituents.						
	S. W. District (Whiston to Towcester).	Main Ironfield (including Earl's Barton and Brixworth).		Rutland and North Northants.	South Lincs.		Mid Lincs.
	Quarried Ore.		Mined.	Quarried Ore.		Ore at mining depth.	Quarried.
	1.	2.	3.	4.	5.	6.	7.
Iron (moist ore)	35·62	32·93	31·06	32·40	33·72	31·00	32·15
Iron (dried at 100° C.) ...	40·83	39·04	35·97	38·21	40·61	36·20	—
Silica (moist ore) ...	14·72	14·29	12·62	15·90	15·28	14·40 (insol.)	17·67 (insol.)
Alumina (,,) ...	5·83	6·18	6·38	6·67	5·54		
Lime (,,) ...	2·51	3·41	3·63	2·13	·71	—	3·58
Magnesia (,,) ...	·27	·34	1·13	·57	·35	—	—
Manganese (,,) ...	·19	·20	·14	·21	·33	—	—
Sulphur (,,) ...	·045	·092	·30	·04	·07	—	—
Phosphorus (,,) ...	·77	·63	·47	·76	·80	—	1·00[1]
Moisture (,,) ...	12·76	15·48	10·98	14·47	17·50	14·60	12·10

1, 3, 4—Averages of several analyses. 2—Average of many analyses. 5, 6, 7—Averages of few analyses.

[1] Only one analysis estimating phosphorus.

Raw Ore, 'as received.'	Comparative Analyses.[1]									
	S.W. District.		Main Ironfield.				Rutland and North Northants.		South Lincs.	Mid Lincs.
	Quarried Ore.					Mined.	Quarried Ore.			
	Richer Ore.	Poorer and calcareous.	Typical.	Richer.	Poorer and calcareous.	Typical.	Richer.	Poorer and calcareous	Typical.	Typical.
Iron (moist ore)	37·18	28·97	33·04	37·92	30·70	30·74	34·0	26·10	34·97	34·57
Iron (dried at 100° C.) ...	43·64	35·58	39·40	43·40	37·08	36·30	42·5	30·28	41·14	39·33
Silica (moist ore) ...	9·47	16·00	15·14	10·29	13·74	8·13	12·5	15·70	15·83)	17·31 (insol.)
Alumina (,,) ...	6·15	6·06	5·18	5·01	3·70	6·01	7·0	8·53	5·89)	
Lime (,,) ...	1·55	5·19	2·00	2·59	5·04	6·23	·6	6·77	·66	2·21
Magnesia (,,) ...	Trace.	·35	·543	·467	·59	1·113	—	·63	·33	—
Manganese (,,) ...	·232	·22	·440	·280	·09	·207	·15	·26	·33	—
Sulphur (,,) ...	·044	·06	·047	·146	·19	·388	·03	·037	·08	—
Phosphorus (,,) ...	·735	·62	·657	·599	·43	·695	·55	·343	·75	—
Moisture (,,) ...	14·80	18·58	16·13	13·56	17·20	15·28	20·00	13·80	15·00	12·10

[1] Actual analyses of the ore, to illustrate variation of quality.

'Gulls' of the kind first mentioned are sometimes a serious inconvenience, and may have the effect of raising the silica-percentage, owing to difficulty of excluding all the sand, as well as reducing the yield of the working.

Chemical Composition.

The accompanying tables (pp. 146-7) give the average values of the chief chemical constituents of the Northampton Ironstone, as deduced from different numbers of partial and complete analyses for different parts of its area; also characteristic analyses of the ore as worked in its mean and extreme qualities.

Compared with the Frodingham and Marlstone ores, the salient chemical characteristics of the Northampton Ironstone are its relatively high percentage of iron, silica and phosphorus, and its relatively low percentage of sulphur, manganese (as compared with the Frodingham ore) and lime (as compared with the Frodingham and the less weathered Marlstone ores). Its small content of lime and its large content of silica render it an essentially siliceous ore in both its oxidized and its unoxidized states, for the lime-percentage of the unweathered carbonate-ironstone is not high enough to make it a really calcareous ore.

A greater difference of composition exists between the weathered and the unweathered ore than might be supposed from the analyses, for much of the stone is quarried under as great a thickness of cover, and in practically the same condition, as the shallower mined ore, while all the mining is done at little depth. Still, the average values (p. 146) do show an appreciable difference in iron-content between the quarried and the mined stones, though a less appreciable difference of lime-content. For the relative richness of the whole bed in iron accentuates the difference of iron-content between the unweathered ore and the weathered, in which the removal of the more soluble constituents has concentrated the iron, while the relatively small percentage of lime in the unweathered ore diminishes the difference of lime-content between the two conditions of the ore.

The slight apparent increase of average iron-content in the south-western district, immediately preceding a general deterioration in the same direction, may possibly result from the local capping of thick sandstone ('Variable Beds,' p. 142). For this sandstone, presumably somewhat ferriferous at an early stage and certainly rather permeable to, than absorbent of, iron, may itself have imparted, as well as transmitted, more iron to the absorbent ore below.

Extent and Limits of the Ore-bed.

The Northampton Ironstone has an extensive distribution in the eastern counties of England (*see* Maps, Pls. V and VIII). Apart from the variable and sporadic Dogger ironstone in a similar position at the base of the estuarine Oolites of Yorkshire, it extends from North or Mid Lincolnshire to the south end of Northamptonshire, and is worked from Lincoln to Towcester at varying intervals throughout a distance of about 85 miles along the outcrop of the formation.

In the extreme north of Lincolnshire the bed, thin and sandy, cannot be regarded as an iron-ore; but from Blyborough, 14 miles north of Lincoln, it begins more nearly to approach the appearance of a workable ironstone, though changeable and of no great thickness.

On the north-west side of Lincoln it is very thin and worthless as an ore; but where the outcrop loops eastward down the Witham valley in the Lincoln gap the ironstone has long been worked, principally on the north side at Greetwell, one mile east of Lincoln.

From Lincoln southward the area of the ironstone may be divided into three unequal divisions, based upon the number and distribution of ironstone-workings and the extent and continuity of proved workable ore in relation to the whole area:—

(i) Northern district: From Lincoln along the outcrop southward to the latitude of Melbourne and Fotheringhay, Northants [north margin of map Pl. VIII: the division approximately coincides with the Northampton-Ironstone area of Pl. VI].

(ii) Main Ironfield of Northamptonshire, southward to a line joining Wollaston, Earl's Barton and Brixworth: eastward and south-eastward slightly beyond the final disappearance of the bed under cover [Pl. VIII].

(iii) South-western district of Northants: to south-western termination of ironstone development, beyond Church Stowe and Towcester [Pl. VIII].

The representation of Northampton Ironstone on the two maps indicates in a general way those areas in which an expectation of workable ore is justified by inference from the number and distribution of the workings and trials, as well by direct proof. Such inference is carried farther in the main ironfield than in the two other divisions, in which workings are fewer and trials more frequently unsuccessful.

In the northern district the areas of worked ironstone are few and isolated; and southward of Grantham, where the outcrop broadens, are found for the most part, not upon the main sheet of the Inferior Oolite outcrop, in which the ironstone-bed lies at or not far from the surface, but upon the much eroded and ragged western fringe, where denudation has widely separated the remnants of the lower beds. Consequently in the region containing most of the workings in South Lincolnshire, Rutland and North Northamptonshire, there can be no question of a continuous area of ore. Attempts to find new tracts of surface-ore in the neighbourhood of the proved areas have often failed, owing partly to complete or partial removal of the bed by denudation, partly to a thick and irregular covering of drift, and partly to local deterioration of the ironstone; and these failures have fostered a belief that nearly all the existing ore has already been found. Nevertheless, recent exploration is tending to suggest a larger area of good ironstone than had been supposed. The limited variability of the ore as worked at intervals throughout a wide region strengthens the suggestion.

As an inference from recent investigations, a large area of more or less continuous ironstone is represented on the map (Pl. V) as extending from Grantham southward to Buckminster and

Stainby, beyond which a broad drift-filled depression separates it from a continuation stretching from Market Overton to Burley. This tract, at present but little worked in Lincolnshire, may develop into an important area of ironstone-production, second in extent only to the main ironfield of Northamptonshire.

A little farther south there was probably an original continuity of good ironstone throughout the tract containing the villages of Ridlington, Wing, Luffenham, Barrowden, Wakerley, and Uppingham.

On the other hand, the ironstone along its outcrop for some 10 miles southward from Lincoln does not quite maintain its quality. Though it has been worked to a small extent at Waddington and Coleby, where it is said to be better in quality than between Waddington and Lincoln,[1] its iron-percentage is rather low and its silica-percentage rather high as a rule. At Leadenham it improves for some distance and has been worked for several years; but southward from there it again deteriorates and appears to be of poor quality from Normanton[2] nearly as far as Grantham.

In its most westerly extension in South Lincolnshire, westward of Denton and Buckminster, it suffers farther deterioration, and though it was formerly worked at Waltham-on-the-Wolds, it proved unprofitable and was abandoned.

At its most easterly point of working in South Lincolshire, at Easton, near Stamford, its silica-content rises to as much as 25 per cent., which, however, does not render it unsuitable for mixing with the calcareous Frodingham ore.

From Wakerley southward to the main ironfield, it appears that no ore has been worked, and little is known of the quality of the ironstone there.

In (i.) the northern division, apart from South Lincolnshire, and in (iii.) the south-western, it cannot be assumed that the ore has a quality serviceable under existing conditions outside the areas actually proved. But in (ii.) the main ironfield of Northamptonshire the number and distribution of the workings and the extent of proved ore warrant the expectation that in general (with certain reservations) the ironstone will prove to be workable, both at the surface and underground, wherever the bed has not been removed by denudation. For the ore, as a rule, does not vary beyond the limits of commercial quality in passing from one working to another. Moreover, in the few mines below the depth of open quarries—at Islip, Cranford, Finedon and Irthlingborough—the unoxidized carbonate-ore retains a good quality; and while mining is at present restricted to a comparatively small area in this district of Northamptonshire, the weathered surface-stone in the other parts of the main ironfield closely resembles that of the mining-area: and the underground stone lies usually at no greater depth. Further, leased areas of considerable size have been more or less completely tested around many of the workings; and the ironstone has been examined at

[1] Capt. Macdakin, 'The Northampton Ironstone Beds in Lincolnshire.' *Geol. Mag.*, New Series, Decade ii, vol. iv (1877), p. 406. *See* also J. Dalgliesh and R. Howse, 'Some Remarks on the Beds of Ironstone occurring in Lincolnshire' *Trans. N. Eng. Inst. Min. and Mech. Eng.*, vol. xxiv, 1874–5, p. 30.

[2] Macdakin, *loc. cit.*

the surface or underground westward and southward from Corby, between Brigstock and Sudborough, between Addington and Finedon, and between Barton Seagrave and Kettering.

This main ironfield (ii) may be more closely defined for the present purpose as bounded roughly by the positions of the following towns and villages, from north-west round by south to north-east:—Rockingham, Wilbarston, Desborough, Brixworth, Earl's Barton, Wollaston, Chelveston, Denford, Lowick, Brigstock and Deene. It has a total area of about 190 square miles, reduced as a possible area of ironstone-production to about 132 square miles by surface-erosion along the valleys.

There are, however, certain small parts of this area in which the ironstone has been found to be absent or of poor quality, and one considerable tract in which its commercial value can be assumed only by analogy of the surrounding ground. On the drift-covered plain between Rockingham and Corby (Northants) boulder-clay rests normally upon the lower beds of the Inferior Oolite; yet locally it rests upon beds below the ironstone as was ascertained by boring on the west side of the railway two miles north of Corby; but there is no reason to suppose this state of things prevalent in the neighbourhood.

A shallow syncline between Brigstock and Geddington trends westward towards Brampton[1]; and borings along a transverse line ceased to reach the ironstone at the expected depth in this trough. There is no ground for doubting the presence and quality of the ironstone there; but in the absence of evidence ironstone has not there been indicated on the map, though included in the estimate of probable reserves.

In certain other tracts on the borders of, and within, the main orefield the ironstone becomes too siliceous for general use under existing conditions, and is not represented as ironstone on the map. This deterioration has been found eastward of a line running from Lowick by Islip village and thence east of the Islip furnaces; though the ore was formerly worked farther east at Woodford and Great Addington, and has proved workable at Denford. Again, between Cranford and Barton Seagrave the ironstone becomes in places siliceous or thin, while on the west side of the Ise valley and the Kettering—Wellingborough railway-line, it has been found too siliceous near Orlingbury and Pytchley, as also west-south-westward from Kettering in the direction of Lamport.

Since in the south-western region a rapid and general deterioration takes place westward of Towcester, Gayton and Duston, and a similar deterioration is believed to extend for a considerable distance north-eastward from Duston and Northampton in the direction of Orlingbury, Pytchley and Kettering, the little explored central area of the south-western part of the main ironfield is not represented on the map as containing ironstone. It probably, however, contains more serviceable ore than is there indicated, because the ironstone seems to be continuously good

[1] *See* Pl. VI., Sect. 1, which traverses this syncline south of Stanion. There is probably a greater extent of Oxford Clay beneath the Drift in this neighbourhood than is shown upon the one-inch map.

on the west and north sides from Spratton and Brixworth to Loddington and Kettering, and is also good on the east side in the neighbourhood of Earl's Barton and Wellingborough.

In the main ironfield, as in the northern division northward to Grantham, ironstone-working, both at the surface and underground, is concentrated principally upon the flat or slightly undulating strata of the broad outer area of outcrop, incompletely isolated by the Nene valley from the final disappearance of the ironstone-bed eastward under cover. Of this area the greater part lies between the valleys of the Nene and its western affluent the Ise. The valley of the Ise completely detaches the south-western part, in which the beds assume a decided dip to east-south-east; and numerous small tributary valleys on the west considerably reduce the extent of ironstone on that side.

Comparatively little ironstone has been worked on the south-east side of the Nene valley, and the ore has not been followed underground.

In (iii.) the south-western district (*see* map, Pl. VIII) the principal area of ironstone extends along the outcrop from Whiston westward by Cogenhoe to the Hunsbury Hill Ironworks between Northampton and Gayton, and continues southward, beyond a broad valley in the Lias, to Towcester. All this area lies south of the River Nene, but a small, though important, extension on the north side has been worked between Northampton and Duston. A line from Duston to Towcester marks the western limit of all recent working. Westward of this line the ironstone appears to become generally too siliceous, though here and there it recovers sufficiently to have been worth using before the wide distribution of ironstone in Northamptonshire was discovered. It was formerly quarried for some years south of Church Stowe and at Culworth (9 miles west of Towcester, outside the area of Pl. VIII); and an attempt has been made to mine it at Steeple Aston[1] in Oxfordshire. With this doubtful exception no ore of commercial value is known at this horizon anywhere south-westward beyond the borders of Northamptonshire.

Little is known about the Northampton Ironstone after it passes finally under the cover of newer formations, but borings and sinkings in search of water[2] show that the ironstone does not persist continuously for any great distance eastward and south-eastward.

In Lincolnshire, the Northampton Ironstone can be represented only by 8 feet 6 inches of 'light rock' amongst clays assigned to the Lower Estuarine Series in a bore-hole at Woodhall Spa[3] (*see* Pl. V). The description suggests the absence of real ironstone and in this is supported by the analogy of other borings and well-sinkings farther south. At Martin; between Martin and Billinghay; at Silk Willoughby; south-west of Haydor; north-west of Haceby; and at two points south-west of Corby (Lincs.), bore-

[1] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iv, 1894, p. 496.

[2] *See* 'Water Supply of Lincolnshire' (*Mem. Geol. Surv.*), 1904; 'Water Supply of Bedfordshire and Northamptonshire,' *ibid.*, 1909; 'Thicknesses of Strata,' *ibid.*, 1916, from which the following data are taken.

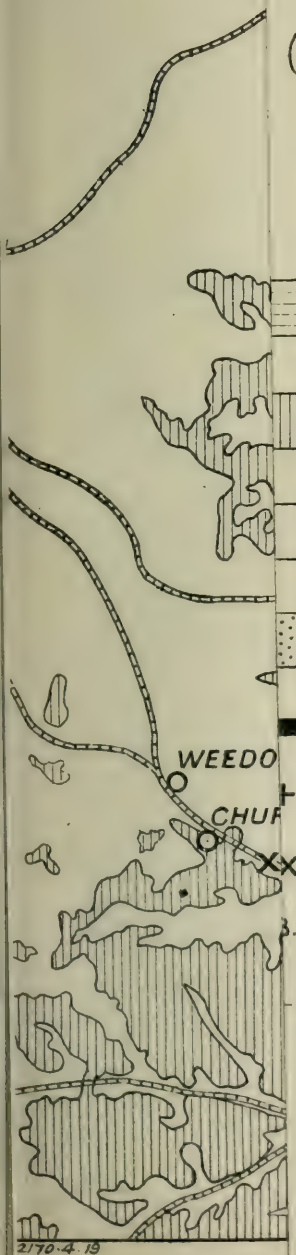
[3] 'Water Supply of Lincolnshire' (*Mem. Geol. Surv.*), 1904, p. 192. The positions of this and of all the following bore-holes and wells are shown on the maps [Pls. V and VIII].

PLATE VIII.

OREFIELDS OF MID & SOUTH NORTHAMPTONSHIRE (NORTHAMPTON IRONSTONE)

Scale of Miles

0 5 10



Middle Oolites.

Lower Oolites with Northampton Ironstone at base.

Lias.

Ironstone.

Ironstone worked out.

Ironworks.

" disused.

B.H. Bore Hole.

------ Broken lines indicate limit of opencast working.

This Sketch map is the southward continuation of the Sketch map Plate V. but is on a slightly larger scale.

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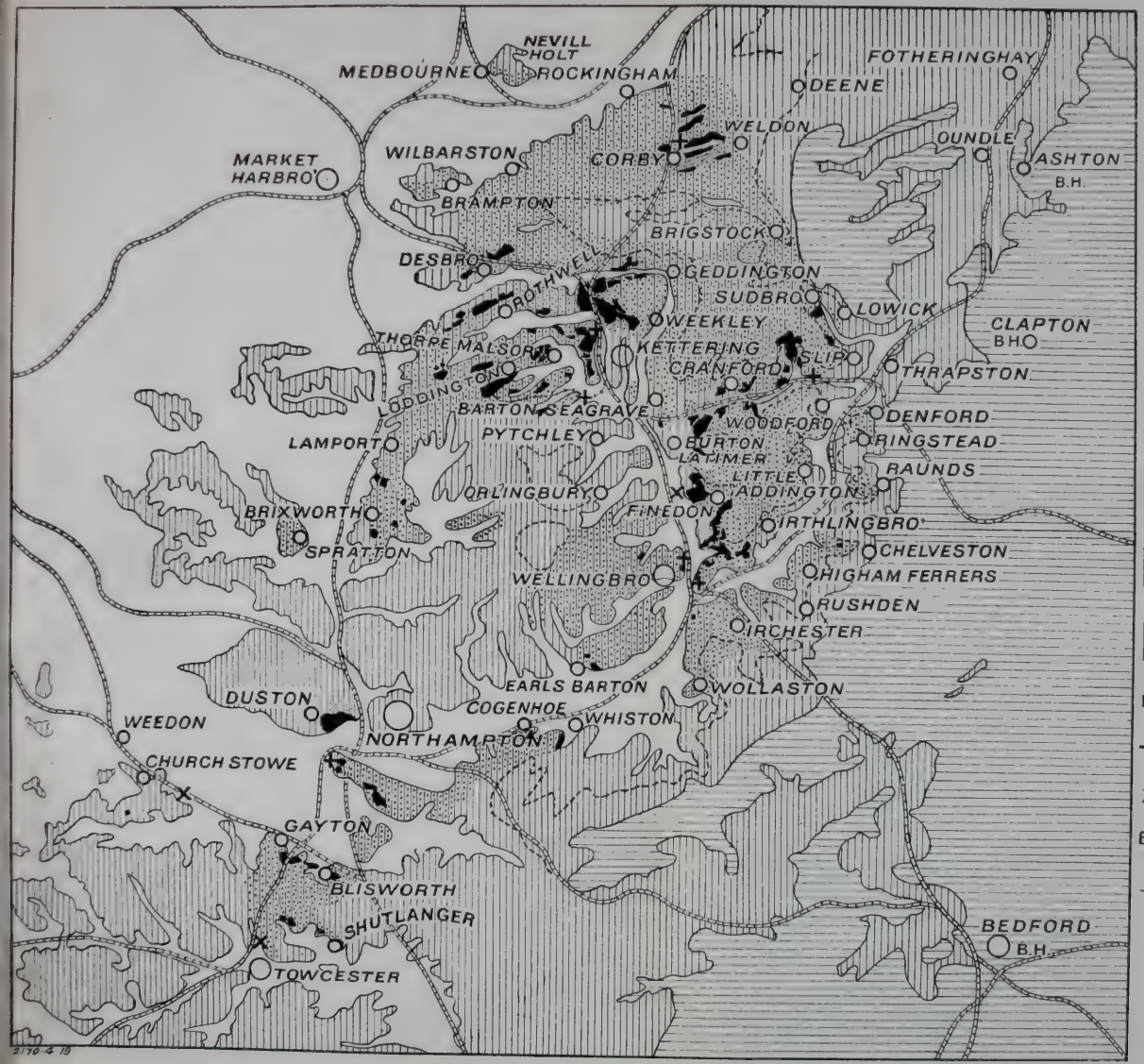
from Geog. Vol. XII to face p. 152

PLATE VIII.



OREFIELDS OF MID & SOUTH NORTHAMPTONSHIRE
(NORTHAMPTON IRONSTONE)

Scale of Miles
0 5 10

- Middle Oolites.
- Lower Oolites with Northampton Ironstone at base.
- Lias.
- Ironstone.
- Ironstone worked out.
- \+ Ironworks.
- X " disused.
- B.H. Bore Hole.
- ------ Broken lines indicate limit of opencast working.

This Sketch map is the southward continuation of the Sketch map Plate V. but is on a slightly larger scale.

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holes and wells have all proved the Lincolnshire Limestone to rest directly upon the Upper Lias clay. Slightly westward of this line of bore-holes and wells, a boring at Digby proved 6 feet 6 inches of clay resting upon 1 foot of rock, between the Lincolnshire Limestone and the Upper Lias; another at Quarrington, 6 inches of clay upon 7 feet of 'blue rock' (there being nothing in this description to suggest real ironstone); and a well at Boothby Pagnal, 9 feet of 'blue sandy limestone' in the same position.

Thus, eastward of the outcrop of workable iron-ore in Lincolnshire the ironstone diminishes in thickness, until at a distance decreasing from 9 to $2\frac{1}{2}$ miles between Martin and the Corby bore-holes the whole group of strata, including the ironstone, between the Lincolnshire Limestone and the Upper Lias, is generally, if not everywhere, missing for 24 miles.

From Castle Bytham, 4 miles south of Corby, to the neighbourhood of Stamford there is no evidence of ironstone having been found either underground or at the surface in the eastern part of the Lower Oolite outcrop.

In Northamptonshire, borings at Glinton and near Marholm, north-west of Peterborough, again show the Lincolnshire Limestone to rest directly upon the Upper Lias. Another at Castor, west of Peterborough, gives $15\frac{1}{2}$ feet of grey sand as representing the whole Northampton Sand above the Upper Lias, the Lincolnshire Limestone having died out; and in this connexion the unusually sandy character of the ironstone at Easton, the nearest working, may be recalled (*see* p. 150). There is, moreover, no ironstone in the beds representing the Northampton Sand on the north side of Peterborough, as proved by borings at New England and Dogsthorpe.

Farther south (Pl. VIII), borings near Ashton and at Clapton again show a complete absence of ironstone in the sands and clays between the Great Oolite Limestone and the Upper Lias; and still farther south, at Bedford, another boring gave the same result. Westward of this line, on the south side of Rushden, the ironstone is recorded as only 3 feet thick.

While perhaps no one of these records is by itself conclusive, the cumulative evidence is sufficient to prove that, even a short distance beyond its final disappearance under cover, the ironstone is absent for many miles in Lincolnshire, and is not persistent continuously in Northamptonshire. In fact, along the line so explored, the above data justify a strong presumption of the entire absence of workable ore from Woodhall Spa, in Lincolnshire, to Clapton, in Northamptonshire. On the question of its possible reappearance still farther east, practically no evidence exists.

In view of the above facts, it would be vain to look for a great development of the Northampton Ironstone under cover south-eastward of its main area merely on the ground of a possible original continuity with the great development of ironstone at the same horizon in Lorraine.

Considering that also in its most westerly extensions in Northamptonshire and Lincolnshire the Northampton Ironstone rapidly deteriorates, it appears likely that the original main area of ironstone-formation at this horizon in the east-midland counties was

much elongated in a general direction slightly east of north, and that it has been exposed without being very greatly reduced by the accident of denudation.

History and Development.

As in the case of the Frodingham ore, abundant Roman slag and other remains have been found in opening up the ironstone in Northamptonshire. Domesday Book mentions 'Ferraria' ['iron-forges,' 'bloomeries'] at Gretton and Corby [Northants] in Edward the Confessor's reign[1]; and also records 'seven foreigners' as having three iron-forges, worth 40s. 8d. yearly, at Castle Bytham in South Lincolnshire, where there is an inlier of Northampton Sand. Later records show that royal furnaces were in work at Geddington from the time of Henry II. to that of Henry III.[2] "In mediæval times, the district of Rockingham Forest vied with that of the Weald of Sussex and Kent as a great iron-producing district. The Norman Castle of Rockingham is said to have been built for the protection of the iron-furnaces. . . . Throughout nearly the whole of the district . . . enormous masses of slag . . . testify to the extent to which the manufacture of iron was carried on in the area in ancient times. . . .

"The causes of the decline of the iron-manufacture in this district were the same as those which operated so powerfully in the case of the Wealden district of the south of England. In the first place, the enactment of rigorous laws to prevent the reckless destruction of timber-trees by the charcoal-burner operated powerfully by restricting the supplies of fuel. In the second place, the discovery of the possibility of smelting iron-ores by means of coal and coke caused the transference of the industry to the coal-bearing districts. . . . For about two centuries the iron-manufacture was thus wholly banished from the district, and scarcely a tradition of its former importance remained."[3]

It was not revived until the latter half of the nineteenth century.

In 1851, or a little earlier, Percy made a rough analysis of a specimen of Northampton Ironstone submitted to him, but did not form a favourable opinion of it as an iron-ore. Shortly afterwards richer specimens were obtained, and on investigation an extensive deposit of ore was found.[4]

In 1855 the Northampton Ironstone was first worked in the neighbourhood of Blisworth and Weedon, at the south-western extremity of the ironstone-area, 74,084 tons of ore being raised in that year.[5]

In 1857 two ironworks (both long since dismantled)—the Heyford Works, near Weedon, with two furnaces, and the East End Works at Wellingborough, with one—had opened, and iron-

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[1] J. D. Kendall, 'Iron Ores of Great Britain,' 1893, p. 41.
[2] *Ibid.*
[3] 'Geology of Rutland' (*Mem. Geol. Surv.*), 1875, p. 110.
[4] 'Metallurgy of Iron and Steel,' p. 225.
[5] R. Meade, 'Coal and Iron Industries of the United Kingdom,' 1882, p. 548.

stone-working had extended to Northampton and Desborough, the total output of ore reaching 140,485 tons in 1858.[1]

In 1859 the ironstone was being got also at Duston, at Cogenhoe (where it was mined by adits[2]), at East End (Wellingborough), and near Stamford, so that it was then known at both ends of the Northamptonshire ore-field.

In 1864 it was being obtained also at Brixworth, Glendon (north of Kettering; it is still one of the most important centres of the industry), and Nevill Holt; while the Heyford works were partly supplied with ore from quarries near Church Stowe, long since abandoned.

In 1866 two more ironworks, the Irthlingborough Works (Wellingborough) and the Glendon Company's works at Finedon, had opened, six furnaces being in blast in Northamptonshire. The Finedon Works were then drawing local ore from Finedon.

By 1872 ironstone-working had extended to Woodford (where the ore was mined[3]), Burton Latimer, Irchester, Irthlingborough, Islip and Ringstead, the Islip furnaces being by then in blast. The Northampton iron-industry may be considered to have become firmly established and general by that time, there being nine furnaces in blast and the ironstone-output having exceeded 1,000,000 tons in 1872.[4] It appears that the chief seat of the industry had passed from the south-western extremity to the central part of the ironfield.

The output of pig-iron increased from 9,750 tons to 178,714 tons between 1858 and 1880,[5] in which year the following works and furnaces were in operation.[6]

Works.	Situation.	Furnaces. Built or building.	In blast.
Cransley	S.W. of Kettering ...	2 ...	2
Finedon	W. of Finedon	5 ...	5
Heyford	S.E. of Weedon	3 ...	2
Hunsbury Hill	S.W. of Northampton ...	2 ...	2
Irthlingborough	E. of Wellingborough ...	3 ...	2
Islip	Near Islip	4 ...	2
Kettering	N.W. of Kettering ...	2 ...	2
Stowe	E. of Church Stowe, near Weedon.	2 ...	0
	Total ...	23	17

The Finedon, Heyford and Stowe works, as well as another works built later north of Towcester, have long since been dismantled.

[1] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*) Meade (*op. cit.*, p. 552) gives the date of opening of the East End Works as early in 1852, and states that Northampton ore was then being used at those works.

[2] Meade, *op. cit.*, p. 539.

[3] *Ibid.*

[4] 'Mineral Statistics of the United Kingdom.'

[5] Meade, *op. cit.*, pp. 555–6.

[6] *Ibid.*, p. 555.

The annual output of Northampton Ironstone in Northamptonshire alone, for every fifth year from 1860, has been as follows:—

(*From Mineral Statistics of the United Kingdom*).

Year.	Output in tons.
1860	95,664
1865	364,349
1870	761,248
1875	1,085,899
1880	1,550,013
(*From Home Office Records*).	
1885	1,160,000
1890	1,278,381
1895	1,082,352
1900	1,622,539
1906[1]	2,250,583
1912[1]	2,527,840
1915	2,517,150

The ascertained areas of ironstone worked out are represented, approximately to scale, on the maps (Pls. V and VIII), which show nearly all the more important areas so worked at any time, as well as all the areas recently worked. But they do not show some of the earlier workings, the extent of which could not readily be traced. Such earlier workings[2] were located at:—

Situation.	Years working.	Situation.	Years working.
(Lincolnshire)			
Washingborough,[3] W. of	1874		
(Rutland)			
Manton	1887	Ridlington	—
(Northamptonshire).			
Culworth (outside Pl. VIII: 9 miles W. of Towcester) ...	1873–7	Raunds[4]	1881
		Ringstead	1872–91
Great Addington (N. of Little Addington)	1881–5, 1891–2	Shutlanger (Shuttlehanger)	1873–4
		Spratton	1877–82
Hardingstone[5] (1½ miles S.S.E. of Northampton) ...	—	Stamford	1859–76 (intermittently).
	—	Thrapston ? ...	1873–? (working in 1881).
Irchester	1872–80, 1893		
Medbourne	1873	Wollaston	1875–? (working in 1881).
Nevill Holt	1864–5		
Northampton ...	1877–?	Woodford	1867–91

Of these only the workings at Irchester, Ringstead, Wollaston and Woodford are likely to have been at all extensive.

Besides these, former working was more extensive than the map indicates at Desborough (from 1856), Cransley (1 mile S.W. of Kettering, 1877-88), Wellingborough (from 1858), Irthlingborough (from 1871), Blisworth (from 1855), Easton Neston (N.E. of Towcester, from 1873), and near Church Stowe (1855-65).

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[1] The figures for 1905, 1910, 1911 include small amounts of other ores raised in neighbouring counties.

[2] From 'Mineral Statistics of the United Kingdom' and Home Office Records.

[3] J. Dalglies'h and R. Howse, 'Some Remarks on the Beds of Ironstone occurring in Lincolnshire,' Trans. N. of Eng. Inst. Min. and Mech. Eng., vol. xxiv, 1875, p. 30

[4] Meade, *op. cit.*, pp. 547 and 552.

[5] *Ibid.*

Apparently a very small amount has been mined at Steeple Aston[1] in Oxfordshire.

Output and Reserves.

The following figures, based upon 'Mineral Statistics of the United Kingdom' and the later Home Office records, may be taken to represent approximately the amount of Northampton Ironstone worked out between the years 1855 and 1916, inclusive:—

	Tons.
Lincolnshire	7,500,000
Rutland	3,500,000
Northamptonshire	77,500,000
Total ...	88,500,000

The figures for Northamptonshire should be reasonably accurate; those for Lincolnshire and Rutland, for which the Home Office returns of ironstone combine different ores from one or more counties, are modified in accordance with estimates based on areas worked out, in relation to assumed average thickness, the result being merely a rough approximation.

At the present time 32 companies or individual employers are working the Northampton Ironstone in these three counties. They comprise nearly all the iron-makers of Northamptonshire, and some of other districts, together with ironstone-companies owned by or affiliated to the iron-producing companies; as well as independent companies or employers raising the ore for sale.

The number of separate workings is three in Lincolnshire; four, of which one is only just starting, in Rutland; and about 54 in Northamptonshire, the definition of a separate working being arbitrary.

The output of Northampton Ironstone in 1917 amounted to[2]:—

	Tons.
Lincolnshire	359,193
Rutland	371,854
Northamptonshire	2,561,459
Total ...	3,292,506

The figures show a considerable increase over those for the preceding year; and the rate of increase was still maintained in the spring of 1918.

An estimate of areas indicated on Pls. V and VIII as likely to contain reserves of Northampton Ironstone of workable quality gives the following figures on the assumption that one acre 1 foot in thickness yields 2,500 tons of ore.[3]

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[1] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. iv, 1894, p. 496.

[2] From the Ministry of Munitions.

[3] The central part of the synclinal trough between Brampton and Brigstock (Pl. VIII) is included, though not shown on the map as iron-ore.

	Total estimated area of unworked ironstone in acres.	Total ironstone content in tons.	For open-cast working (tons).	For mining	
				Total (tons).	Minus loss of 10 per cent. for pillars. (tons.)
Lincolnshire ...	23,750	475,000,000	54,000,000 (at least)	66,000,000 (at least; probably much more)	59,000,000
Rutland	5,900	118,000,000[1]	(nearly all opencast)	(little).	—
Northamptonshire	80,400	1,715,000,000	1,182,000,000	533,000,000	480,000,000
Total ...	110,050	2,308,000,000			

In these estimates no allowance is made for ore left as a roof in mining: so far, such ore has not always been recovered, though, generally speaking, it probably could be.

The estimated area in South Lincolnshire (Pl. V) may conveniently be divided thus:—

(i) Area lying mainly in the triangle between the villages of Buckminster, Stainby and Skillington, where there is good evidence of large reserves at or close to the surface: estimate 51,000,000 tons.

(ii) The rest of the estimated area northward to Stoke (Rochford), in which exploration has been fairly adequate: a small part west of Skillington would certainly have to be mined; but in much of this ground open working or mining might be optional: estimate 112,000,000 tons, from which 5–6,000,000 tons should be deducted for loss in pillars if half this area were mined.

(iii) A farther area northwards to Grantham, in which exploration has not been adequate, but indications support a continuance of good ore: some of this eastward of the main valley would necessarily require mining, and probably much more of the area would be mined: estimate 288,000,000 tons, from which 14–15,000,000 tons should be deducted for pillars, if half the area were mined.

In Mid Lincolnshire some of the ground between Leadenham and Lincoln, a tract much of which contains ironstone not far below a profitable commercial standard, may prove to contain workable ore; which may also exist locally, but not everywhere, north of Lincoln as far as Blyborough.

Again, mainly in Rutland, it is possible that considerable unproved reserves may exist between Ketton (Rutland) and Stainby (S. Lincs.), but in view of the probable eastward deterioration of the ironstone in that neighbourhood, it would be unwise to count on such reserves.

In North Northamptonshire a considerable tract of unproved ground lies between Weldon (Pl. VIII.) and Wakerley (Pl. V), and is quite likely to contain areas of workable ore.

For the most part all such areas are excluded from the above estimates. Nor in them is any account taken of possible reserves existing beyond the final disappearance of the ironstone under cover eastward and south-eastward of the Nene valley in Northamptonshire.

From these estimates and from those of output on p. 157 it follows that less than one twenty-third part of the total ironstone-content of the Northamptonshire ironfield has been got out in the

[1] This estimate includes certain areas proved and leased since the estimate published in 'Summary of Progress for 1917' was made.

62 years from 1855 to 1916 inclusive, and less than one twenty-sixth part of the total Northampton Ironstone in the three counties; also that at an annual output of 3,000,000 tons the reserves of the same ironstone in these counties should last rather more than 760 years.

Methods of Working.

The maps (Pls. V and VIII) show at a glance that the distribution of the ironstone-workings depends mainly upon the railways, which themselves for the most part follow the principal river-valleys, on the flanks of which the ironstone-bed crops out. Consequently opencast working starts usually at the outcrop of the bed in the close proximity of a railway, and mining, where done at all, is carried on by adits from the outcrop.

By far the greater part of the output is obtained by open working under an amount of cover varying from 1 or 2 feet up to a maximum of about 45 feet. A thickness of 20-30 feet of cover is quite commonly removed. This cover, where at all thick and not composed of Glacial drift, usually consists largely of the white and rather pure quartz sand of the Lower Estuarine Series. The sand is generally treated as waste material, but in one case it is sold for 'pug-ganister,' and perhaps elsewhere might be disposed of profitably.

The nature of the cover may determine the method of working as between opencast and mining, for some of the stone is mined at less depth than the deepest opencast. The value of the limestone above, whether Lincolnshire Limestone or Great Oolite, for fluxing or other purposes may be decisive in favour of open working; or the hardness and intractability of some beds may necessitate mining at a very shallow depth. On the whole, a depth of about 40 feet may be taken to mark the division between opencast and mining areas.[1]

In the majority of workings at the present time the cover is removed and the ironstone worked entirely by hand; but in the deeper open workings and in most of the larger, machinery is commonly used for removing the cover; but seldom for the ore. At the present time the tendency is to extend the use of steam-diggers for both cover and ore, but in some places the limestone of the cover may be too strong for the steam-digger, which in any case would scarcely be used where the limestone is required for fluxing and must not be mixed with the sands or clays below. Blasting is not usually needed.

The method of working the ore aims at obtaining it in a condition suitable for the furnace; and in view of the varying hardness of the weathering ore, this consideration probably explains the general, but not universal, preference for hand-labour. In one case the steam-digger is said to give better results owing to the brittle character of the ore. Generally the whole thickness is got from top to bottom by pick and shovel in one course. In a few quarries the soft lower part is extracted with the pick and the

[1] The broken line drawn on the maps aims at separating ground that is mined or that must necessarily be mined, within or eastward of the line, from the rest of the ironstone area, and does not mark a constant depth of 40 ft.

rest prised down with crowbars, in masses of 20 tons or more, which break automatically into fragments suitable for the furnace.

At the present time mining is carried on only in that part of the main ironfield of Northamptonshire which lies in the angle between the rivers Nene and Ise, southward from Cranford and Islip. Mining has also been done in recent years alternatively with opencast working at Lincoln. In former years the ore was mined at Woodford and Cogenhoe (*see* p. 155), and for a short time at Coleby in Lincolnshire. All mining is done by adits, on the pillar-and-stall system. Blasting is usually necessary.

The ironstone has no good roof as a rule; and some of the upper stone is left in to make a roof; but the stone so left may be exceptionally less than 1 foot, and may be recovered finally. In the extreme south-western district, between Towcester and Northampton, the only part of the ironfield where the ore is likely to have a good natural roof in the sandstone there overlying it, no mining has yet been attempted.

The general distribution of the ironstone-workings in relation to the main railways has been noted above. In a few cases, however, the construction of standard-gauge mineral lines, *e.g.*, that from Kettering to the Cransley furnaces and the Loddington quarries, and the new line from Grantham through the ironstone-area of South Lincolnshire, has facilitated the working of ironstone at a greater distance from the main railways. In other cases short standard-gauge lines, owned either by the railways or by the companies working the ore, run from railway-sidings to the quarries, the ore being loaded direct into standard-gauge trucks. More commonly the ore is loaded into tubs running on narrow-gauge rails, in some cases to a gravitation-plane or an aërial ropeway. In the newest mines small electric engines are used for haulage.

Treatment of the Ore.

Calcining is done sometimes in kilns, but from South Lincolnshire southward more usually in the open in heaps, containing each, it may be, as much as 50,000 tons of ore. In these calcining-heaps, known in some parts as 'clamps,' a layer of coal is usually, but not always, laid at the base, above which raw ore and slack are generally tipped alternately in sloping layers, or less frequently spread horizontally. The weight of coal and slack required is remarkably small in proportion to the amount of ore calcined. The practice of calcining in the open has persisted in the case of the Northampton ore, while for more calcareous ores it has been discarded, as rendering them too friable (*see* Frodingham Ironstone, p. 84).

In consequence of its amount of silica and phosphorus, and its deficiency in manganese, the Northampton Ironstone naturally produces a somewhat siliceous but fluid iron adapted for such foundry-work as the making of pipes and small castings in which sharply defined detail is required; and in normal times it has been used chiefly for the production of foundry-iron of this class and of forge-iron, the character of the metal being controlled to a certain extent by furnace-management. For these purposes the

Northamptonshire furnaces use Northampton ore alone without admixture of other ores. But the local variation of this ironstone gives some scope for adapting the furnace-mixture to requirements by blending.

The Northampton ore is sent to Leicestershire, Nottinghamshire, Derbyshire, Yorkshire, and South Lancashire, for mixing with less siliceous ores, as well as to South Staffordshire and Warwickshire, where it is employed largely in combination with the calcareous Oxfordshire ore.

The abnormal conditions of the present time, however, demand the production of basic pig for steel-making, and for this the siliceous Northampton ore requires the addition of manganese-ore or manganiferous tap-cinder, the manganese-ore so used being obtained principally from India and Wales. In one or two cases a small proportion of calcareous Marlstone ore from Oxfordshire is added. Besides this recent local practice, Northampton Ironstone is now being used also in South Wales for steel-making, without admixture of other iron-ore.

The flux for the Northamptonshire and Leicestershire furnaces is supplied by the limestones above the ore, the Lincolnshire in the north and the Great Oolite Limestone southward of Kettering. The purer Lincolnshire Oolite makes a better flux than the rather siliceous Great Oolite Limestone. The Nottinghamshire and Derbyshire furnaces that use Northampton Ironstone mixed with Marlstone ore, have the advantage of fluxing with the local Carboniferous Limestone, regarded as a better flux than the Lincolnshire Oolite, though little purer.

Where the calcareous Marlstone ore of Oxfordshire is mixed with Northampton ore, the addition of limestone is not always required. The Northampton mixed with Frodingham Ironstone is self-fluxing.

The following seven ironworks are now in operation in Northamptonshire: —

Works.	Site.	Owners.
Corby	Corby	Lloyd's Ironstone Co., Ltd.
Cransley	S.W. of Kettering ...	New Cransley Iron and Steel Co., Ltd
Hunsbury Hill ...	S.W. of Northampton	Exors. of the late P. Phipps.
Irthlingborough ...	Wellingborough, east side	Thos. Butlin & Co., Ltd.
Islip	S.W. of Islip	Islip Iron Co., Ltd.
Kettering	Kettering, N.W side...	Kettering Iron and Coal Co., Ltd.
Wellingborough ...	Wellingborough, N.E. side	Wellingborough Iron Co., Ltd.

According to the Home Office Records there were 20 furnaces in Northamptonshire in 1916, of which eleven were in blast. In that year the total amount of pig-iron made in the county was 284,520 tons, produced from 854,002 tons of ore,[1] the balance of the total 2,022,121 tons raised representing the amount of ore sent to other districts.

[1] Home Office Records.

Local Details: Lincolnshire.

The most northerly workings of the Northampton Ironstone in Lincolnshire are at Greetwell on the east side of Lincoln, where the Mid-Lincoln Ironstone Co. have long worked this ore. The amount already raised here amounts to more than 4,000,000 tons. About two-thirds of the output is obtained by shallow mining in ordinary times; but since the beginning of the war the ore has been got by opencast, the choice of method being determined mainly by the prospect of disposing profitably of the overlying Lincolnshire Limestone. Recently large quantities of the lower hard limestone have been supplied for road-material, while the softer and purer beds above are sold for lime-making.

As these are the nearest workings of the Northampton Ironstone to the Frodingham ironfield, the output, which amounted to 3,000 tons a week before the war, is used for mixing with the Frodingham ore.

The ironstone-bed crops out along its normal strike on the west side of Lincoln; but in the Witham valley it remains at the surface for a considerable distance eastward of Lincoln; and at Greetwell is worked from its outcrop on both sides of a small tributary valley north of the Witham. As the eastward fall of the ground nearly keeps pace with the dip of the beds, mining is at very shallow depths, and the amount of cover in the Greetwell workings ranges from 6 ft. to about 50 ft.

The full thickness of the ironstone varies as a rule between 9 feet and 10 feet and rarely exceeds 12 feet. It thins somewhat rapidly westward of the workings and is said to thin also northward and eastward.

The following measured sections illustrate the character of the ironstone and overlying beds:—

Section South of Louth Road, ¾ mile E.N.E. of Lincoln Cathedral.

	Thickness. Ft.	In.
Lincolnshire Limestone (Inferior Oolite)—		
Limestone rubble	3	0
Fine-grained compact cream-coloured limestone, thin-bedded, with few ooliths	5	0
Similar limestone, but harder and thicker-bedded: bottom bed brown	5	0
(The above limestones sold for lime.)		
Hard massive, slightly oolitic limestone, blue-hearted, weathering cream-coloured (sold for road metal)	3	0
Hard massive more oolitic and shelly rag-like limestone, pale pinkish-buff (sold for road metal)	2	6
Northampton Ironstone—		
Brown moderately hard decalcified finely oolitic ironstone, with deposit of brown ferric oxide along joints and bedding-planes ('box structure'): up to	1	10
Soft brown finely oolitic ironstone, with little 'box-structure,' up to	0	8
Brown finely oolitic ironstone with many tabular layers of brown oxide, variable, up to	0	9
Brown oolitic massive ironstone with 'box-structure,' up to	1	6
Dark grey and dark brown very finely oolitic ironstone, rather soft	0	6
Brown rather soft, very finely oolitic ironstone, with close 'box-structure'	1	6
Dark grey soft finely oolitic ironstone	0	7
Dark brownish-grey harder finely oolitic ironstone	0	9
Grey, softer rubbly-looking finely oolitic ironstone, about ...	1	6
Actual total thickness of ironstone, about 8 ft. 6 in.		

Section in working on north side of road to Fiskerton, about 1 mile east of Lincoln Cathedral.

	Thickness. Ft.	In.
Lincolnshire Limestone (Inferior Oolite)—		
Soil and limestone rubble ... ... 12 ft. to	16	0
Massive fine-grained yellowish-brown limestone, 3 ft. 3 ins. to	0	10
Massive oolitic limestone, mottled pale pink and blue ...	1	8

	Ft.	Ins.
Lower Estuarine Series—		
Soft yellowish-brown calcareous and sandy clay	0	2
Soft grey silty marl	0	5
Northampton Ironstone—		
Brown ironstone with 'box-structure' and laminæ of dark shaly clay	0	3
Brown soft ironstone not visibly oolitic	0	3
Dark brown and yellowish brown harder ironstone, with small 'box-structure, including soft marly cores... ...	3	6
Layers of dark brown ferric oxide interbedded with paler marly ironstone ... ... 3 ins. to	0	5
Brown hard marly ironstone with crusts of ferric oxide ...	1	6
Brown marly ironstone, hard and soft, with box structure: also a few blue cores, some soft, some hard (only the harder and fresher cores retain a fine-grained oolitic structure)	2	6
Upper Lias—		
Blue clay	—	

Total ironstone, about 8 ft. 5 in.

None of the ironstone in this section keeps its oolitic structure, except the less weathered cores.

It is noteworthy that in both these sections, as generally in the immediate neighbourhood, the Lower Estuarine sands and clays are either absent or represented by merely a few inches of clay.

The lowest bed of the ironstone frequently contains phosphatic nodules, which elsewhere in the neighbourhood south of Lincoln are aggregated in a 'coprolite-bed.'

The following is an analysis[1] of the Greetwell ironstone :—

Raw ore, as received.	*Per cent.*
Iron	33·81
Iron (dried at 100° C.)	37·92
Silica	16·75
Alumina	6·28
Lime	3·37
Magnesia	·72
Manganese	·20
Sulphur	·15
Phosphorus	·50
Moisture	10·85

Other analyses of this ore give :—

Raw ore, as received.	
Iron	33·0—34·5
Silica	14·0—18·0
Lime	4·0— 8·0

The ore as mined at Greetwell naturally contains the maximum of lime, as well as having much of its iron in the ferrous state as carbonate. Only the blue carbonate ore is calcined, in kilns, at Greetwell.

The ironstone was worked as long ago as 1874 on a small scale also south of the Witham near Washingborough, where there may be a considerable reserve, for the estimation of which however no data are available.

[1] From F. H. Hatch. 'Average Analyses of British Iron-ores and Ironstones produced in 1917-18' (*Ministry of Munitions of War*), 1918.

At the same date it was being worked eastward from its outcrop on the north side of Waddington, 4 miles south of Lincoln. The old quarry shows:—

	Ft.	Ins.
Soil ... ... about	1	6
Lincolnshire Limestone—		
Limestone	5	0
Passage-bed of partly decalcified sandy limestone flags	1	3
Sandy oolitic ironstone, with 'box-structure,' seen for	5	6
(Bottom of ironstone not seen.)		

Farther south, beyond Coleby village, where the ore was mined eastward from the outcrop, at about the same date, the following section of the mine shaft has been published[1]:—

	Ft.	Ins.
[*Lincolnshire Limestone* (*Inferior Oolite*)—]		
Lincoln Oolite	45	0
[*Northampton Ironstone*—]		
Peroxide	0	8
Clay mixed with Ironstone	0	4
Hard blue Ironstone	0	9
Clay Parting	0	3½
Hard blue Ironstone	1	4
Peroxide Girdles	0	1
Soft blue Ironstone	0	9
Nodule bed, blue	0	5
Parting	0	0½
Ironstone Nodules, blue	0	6
Blue siliceous Ironstone	1	1
Blue Nodule-bed	0	6
Clay with Nodules	3	0
Coprolite Bed	0	3
[*Upper Lias*—]		
Blue Lias clay	—	
Total Ironstone, 10 ft.		

An analysis of this ore was given in the same paper, as follows:—

	Per cent.
Peroxide of iron [=Iron 40·64]	58·06
Protoxide , ...	—
Protoxide of manganese	·02
Alumina	6·10
Lime	2·94
Magnesia	·89
Carbonic acid	1·87
Silica	13·17
Sulphur	trace
Phosphoric acid	·80
Water combined	11·86
Moisture	4·29
	100·00

The high percentage of iron and the small proportion of moisture suggest that the analysis was done on the dried ore or on a dried specimen. In that case, the presence of 15 per cent. of moisture would reduce the iron-percentage to 36·09.

It seems that no great output of ore was obtained from this mine before operations were abandoned.

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[1] J. Dalgliesh and R. Howse, 'Some Remarks on the Beds of Ironstone occurring in Lincolnshire,' *Trans. N. of Eng. Inst. Min. and Mech. Eng.*, vol. xxiv (1874–5), Pl. xi.

The Northampton Ironstone is now being worked at its outcrop at Leadenham (Major G. Dove), 14 miles south of Lincoln. The cover, chiefly limestone, of which the lower beds are sold for road-metal, and higher beds for cement-making, amounts to a maximum of 25 ft. at present, and the ironstone averages 7 ft. in thickness, between limits of 6 ft. and 7 ft. 6 ins.

The working face, 900 ft. in length, showed the following sequence at a point near its middle:—

	Thickness. Ft.	ins.
Lincolnshire Limestone (Inferior Oolite)—		
Limestone, rubbly, about	5	0
Limestone, fairly massive, up to	10	0
Lower Estuarine Series—		
'Sand'	2	0
Blue clay	1	0
'Cleanings'—an irregular bed of good oolitic ironstone (up to 1 ft. in thickness), like the top bed of the main ironstone below, in blue clay	1	6
Northampton Ironstone—		
Oolitic ironstone, brown on the whole, but with some irregular and impersistent blue cores, somewhat calcareous, individually up to 1 ft. or 1 ft. 6 in. in thickness: some 'box-structure: thickness ... ... 6 ft. to	7	6
Upper Lias—		
Blue clay, not seen	—	

Farther south in the same working the Estuarine Beds are thicker:—

Limestone	—	
Lower Estuarine Series—		
Light brown loamy marl	2	6
Blue clay with band of ironstone (6 ins. to 8 ins.), apparently representing the 'cleanings' of the other section, in middle	2	9
Northampton Ironstone—		
Oolitic ironstone	—	

In working the ironstone, only the harder and more calcareous blue cores are rejected. The output of ore goes to Frodingham. No calcining is done at Leadenham. Working is expected to extend eventually farther northward, and for a less distance southward.

A partial analysis[1] of the ironstone is as follows:—

Raw ore, as received.	per cent.
Iron	30·50
Iron (dried at 100° C.)	34·52
Silica	19·10
Lime	3·61
Moisture	11·64

From Leadenham southward to the Holwell Co.'s Buckminster workings, a distance of more than 16 miles, the Northampton Ironstone has as yet nowhere been worked.

On the east side of Grantham, where indications first suggest a return of that ironstone to a workable quality, after an interval of several miles, in which it has deteriorated, a well[2] sunk at Lowe's Farm, Belton Ashes, three miles N.E. of Grantham, passed through 15 ft. of 'red rock' (Northampton Sand) between the Lincolnshire Limestone and the Upper Lias clay.

[1] From F. H. Hatch, *op. cit.*

[2] 'Water Supply of Lincolnshire' (*Mem. Geol. Surv.*), 1904, p. 47.

Along the outcrop thence southward beyond Grantham abundant indications of the ironstone suggest ore of fairly good quality. At the Grantham Waterworks, Saltersford, south of Grantham a section at the north-east corner of the reservoirs showed :—

	Ft.	ins.
Lincolnshire Limestone (Inferior Oolite)—		
Limestone, stepped and slipped	—	
Lower Estuarine Series—		
Pale blue sandy clay obscured by slipping of limestone, but at least	2	0
Brown oolitic ironstone, slipped and much jointed, with 'box-structure' and cellular weathering : thickness obscured but said to be at least ... ... 6 ft. or	7	0

Where the outcrop cross s the Great North Road in the rise of Spittlegate Hill about half a mile to the north-west, the ironstone, partly seen, is said to be about 9 ft. thick.

Farther south, one mile and a half west of Colsterworth, a trial-shaft was sunk in 1916 by the Frodingham Iron and Steel Co., in the bottom of an old limestone-quarry 100 yds. north of the cross-roads, and one mile south-east of Skillington. The following section was measured in the shaft and the quarry above :—

	Thickness. Ft.	ins.
[In quarry].		
Soil ... ... 8 ins. to	1	6
Lincolnshire Limestone (Inferior Oolite)—		
Limestone	23	0
[In digging at top of shaft]		
Limestone	5	0
[In shaft]		
Collyweston Slate ?, basal beds of Lincolnshire Limestone—		
Blue clay, weathering yellow	1	0
Blue sandy limestone, weathering yellow, with ferruginous sand and clay-partings	2	0
Lower Estuarine Series.		
Yellow loamy clay, with bands of sand and clay	2	3
? Northampton Sand with Ironstone—		
Calcareous marl [blue or green, rather hard, calcareous, ferriferous, argillaceous and sandy]	2	10
Grey limestone [brittle and splintery] with partings : shells [several species of lamellibranchs]	1	0
Soft calcareous, marly [and ferriferous, blue or green] stone, with clay-partings	4	0
Blue clay, plastic	1	3
Brown clay-parting	0	2
(Workable ironstone)—		
Blue hard ironstone, with brown soft ironstone in parting [at bottom]	0	5
Blue hard ironstone, with brown soft ironstone in parting [at bottom]	0	7
Blue hard ironstone [variable in thickness, about] ...	2	9
Brown soft ironstone in parting [variable, up to]	0	6
Blue hard ironstone	3	7
Brown soft ironstone	0	2
Blue hard ironstone	1	5

(*Workable ironstone*)—continued.	Ft.	ins.
Brown soft ironstone in parting	0	2
Blue hard ironstone	1	5
Brown soft ironstone in parting (*base of workable ironstone*)	0	2
Poor ironstone, hard, with shells; dense and apparently impervious to water [blue or green very fine-grained ferriferous and calcareous sandstone, with *Terebratula*]	3	0
Upper Lias—		
Hard laminated clay, impervious to water...	—	

All beds of the workable ironstone are oolitic. The following figures[1] give the average percentage of three of the more important constituents of the ironstone-bed at the trial-shaft :—

Thickness of workable ironstone.	Moisture.	Iron (Moist stone)	Iron (dried stone).	Insoluble (dried stone).
ft. ins.	per cent.	per cent.	per cent.	per cent.
10 2	14·6	31·0	36·2	14·4

The iron-content of some of the soft brown bands amounted to as much as 37 per cent. (moist) or 43·6 per cent. (dried).

The abnormal nature of the upper beds that appear to represent the top of the Northampton Sand formation above the workable ironstone, as compared with the sequence at Buckminster a mile and a half to the south-west, and with the general sequence southward as far as Northampton, may mark the beginning of an eastward change on approaching the line along which all beds between the Upper Lias and the Lincolnshire Limestone disappear eastward in South Lincolnshire (*see* above, pp. 152-3, and Pl. VI, Sect. 2).

In another trial-hole half a mile east south-east of the above shaft, in the Woolsthorpe valley west of Colsterworth, about 10 ft. of blue and brown oolitic ironstone, resting on brown ferruginous sandstone, was overlain by about 5 ft. of limestone rubble, with a remnant of Glacial drift, and afforded no real indication of the sequence above the workable ironstone. In the case of other trials a little farther east in the same valley no information was obtained as to the nature of the beds between the ironstone and the limestone above. The average iron-content[2] of the ore of several such trial-holes in the Woolsthorpe valley was 33·9 per cent. in the moist stone and 40·7 per cent in the dried.

The Holwell Iron Company lease a large area in the neighbourhood of Buckminster and Stainby and work the Northampton Ironstone on the west side of a north-westerly fault passing through Stainby and bringing the ironstone to the surface on the west side. A section at the north end of the east face of this working, immediately west of Stainby village, showed the following sequence : but the lower part of the ironstone there and elsewhere in this working was obscured by a talus of broken ore owing to the use of the steam-digger :—

	Ft.	ins.
Soil, about	2	0
Pale buff-weathering shaly clay, about	3	0
Band of brownish-grey, apparently carbonaceous clay ...	0	2
Tough pale-blue laminated clay	2	6
Rather sandy-looking brown oolitic ironstone with cellular weathering, and box-structure of brown ferric oxide, about	0	8
Brownish-grey shaly clay parting, variable up to... ...	0	4
Brown oolitic ironstone, with cellular weathering as rather pale cores surrounded by crusts of brown oxide	2	0
More massive ironstone with 'box-structure' seen for ...	4	6

[1] From the Frodingham Iron and Steel Co., Ltd.

[2] *Id.*

The bottom of the bed was not exposed. The general working-thickness of ironstone is 10 feet—11 feet, the thickness of cover only about 6 feet, there being no limestone and no appreciable quantity of drift.[1] The following analyses represent the chemical composition of the Buckminster ironstone :—

Raw ore.	I.*		II.*	III.†	
	As received.	Dried at 100° C.	As received.	As received.	Dried at 100° C.
Iron	34·97	41·14	32·80	33·30	40·00
Silica	15·93	18·62	14·50	15·46	18·55
Alumina	5·89	6·93	5·10	6·18	7·42
Lime	·66	·78	·62	·87	1·04
Magnesia	·33	·39	·33	·32	·38
Manganese	·33	·39	·33	·26	·31
Sulphur	·08	·09	·07	·05	·06
Phosphorus	·96	1·13	·75	·55	·66
Moisture	15·00	—	20·00	16·67	—
Loss on calcination ...	10·12	11·90	—	—	—

* From the Holwell Iron Co., Ltd. † F. H. Hatch, *op. cit.*

All working is open-cast, and the ore is calcined in the open in large heaps or 'clamps' containing each as much as 50,000 tons.

Recent explorations suggest that the area of workable ironstone might be extended westward and west-south-westward from Skillington to the edge of the Inferior Oolite outcrop, about a mile farther in those directions than the representation of ironstone upon the map (Pl. V).[2]

Local Details : Leicestershire and Rutland.

The Northampton Ironstone was formerly worked for a short time at Waltham-on-the-Wolds, in Leicestershire, some distance f rther west than anywhere else in the northern half of its outcrop. The first recorded output from Waltham is for 1882,[3] and work there had been abandoned in 1885,[4] on account of the inferior quality of the ore, for it is poor in iron and excessively siliceous. 'Analyses varied much, the average showing iron 20 p.c., silica 50 p.c., moistures 10 p.c.'[5]

The following is an analysis[6] of the Waltham ore :—

Raw ore (? dry specimen).

	Per cent.
Iron	23·17
Silica	55·01
Alumina	7·76
Lime	trace.
Magnesia	·16
Manganese	·21
Sulphuric acid	·05
Phosphoric acid	·15
Water	5·51

The ironstone was worked at the surface, under little or no cover.

[1] From the Holwell Iron Co., Ltd.

[2] From information supplied by the Holwell Iron Co., Ltd., after the map had been prepared.

[3] Home Office Records.

[4] 'Geology of the South-west Part of Lincolnshire,' (*Mem. Geol. Surv.*), 1885, p. 47.

[5] *Ibid.*

[6] *Op. cit.*—re-arranged.

In Rutland, at Market Overton, 3 miles south of the Buckminster workings and separated from them by a drift-covered tract, Messrs. James Pain, Ltd., work the same ironstone at the surface. Of the Company's three quarries at Market Overton two, viz., No. 2 on the north-west side of the village, and No. 1 some distance south-east of it, are now working, the third or Park pit, immediately east of the village, not being in work. In No. 2 pit, working northward, the cover averages six feet, consisting of sand and clay (Lower Estuarine), and is removed by hand. The whole ironstone-bed averages 11 feet, down to the Upper Lias clay, and does not vary much in thickness. The middle of the bed is regarded as the best part; but on the whole the ironstone is of uniform character and weathered brown throughout. A few 'clay-gulls' of the overlying clay let down into 'pockets' in the ironstone, have to be rejected. The ore is worked, in one lift, by steam-digger.

In No. 2 pit, which works westward, the thicknesses of ore and cover are much the same as in No. 1, but the ironstone diminishes in thickness towards the south end of the working, where it crops out at the surface. It is considered of rather better quality than that of No. 2 pit, as it is rather less sandy and of even quality throughout. It shows much 'box-structure' of brown ferric oxide along joints and bedding-planes, the horizontal layers of brown oxide predominating locally, as well as a smaller cellular structure of weathering. In some parts of the ore the ooliths have decayed into hollow shells, from which the iron has evidently gone to enrich the matrix and layers of oxide; other parts of a lighter brown colour show the crowded ooliths intact. About one foot of pale bluish-green calcareous and ferriferous sandstone at the base, immediately above the Upper Lias clay, is rejected.

There are several 'gulls' of the Estuarine clay descending from above into pockets, and one or two others in which the Upper Lias clay is pinched up from below into sharp anticlines. Where these latter occur, the ironstone above has been planed off level, apparently by Glacial action, and the upper parts of the ironstone have been broken up and have passed into the cover.

The same methods of working are employed as in No. 2 pit.

The following partial analyses[1] give the chief chemical characteristics of the Market Overton ore of Messrs. Pain's three pits:—

Raw ore, as received.

	No. 1 Pit.	No. 2 Pit.	Park Pit.
Iron	32·0	31·0	32·0
Silica	14·5	15·0	15·0
Lime	1·0	1·3	1·3
Phosphorus ...	1·0	·99	·98

These analyses suggest that the ore of the Park Pit is practically identical in quality with that of No. 1 Pit.

The following is a fuller analysis[2] of the Market Overton ore:—

Raw ore, as received.	Per cent.
Iron	34·29
Iron (dried at 100° C.)	40·80
Silica	15·10
Alumina	1·95
Lime	1·45
Magnesia	·57
Manganese	·37
Sulphur	·07
Phosphorus	·53
Moisture	15·95

The ore raised at Market Overton goes chiefly to distant iron-manufacturing districts.

The ground adjoining Messrs. Pain's lease on the south is held by the Sheepbridge Coal and Iron Co., Ltd., who work the Northampton Ironstone at Cottesmore, where it was first opened up in 1882.[3] The ore lies practically flat, under cover varying between 5 feet 6 inches and 6 feet 6 inches of boulder-clay. The ironstone, as worked, averages 8 feet, between extremes of 7 feet 6 inches and

[1] From the Ministry of Munitions.

[2] From F. H. Hatch, 'Average Analyses of British Iron-Ores and Ironstones produced in 1917–18' (*Ministry of Munitions of War*), 1918. Name of pit not given.

[3] Home Office Records.

8 feet 6 inches. It is weathered brown all through, without any blue cores, and is more massive-looking than elsewhere in the neighbourhood. Most of it is densely oolitic, with much 'box-structure' and smaller cellular structure. At the north end of the working, where it is regarded as best, it is unusually dry. About 1 foot of stone at the bottom of the working-face is regarded as too siliceous for use. It is 'holed out' with the pick and the rest is then prised down with crow-bars in masses up to 20 tons in weight, which break in falling. The cover also is removed by hand. Beneath the floor of the pit is 5 feet or 6 feet of 'mere sandstone,' not exposed.

Analyses :—

Raw ore, as received.	I.[1] per cent.	II.[2] per cent.	III.[2] per cent.
Iron	29·45	28·75	34·0
Iron (dried at 100° C.)	35·79	—	[42·5]
Silica	17·70	24·40	12·5
Alumina	10·12	11·70	7·0
Lime	3·30	1·68	·6
Magnesia	·60	—	—
Manganese	·24	·317	·15
Sulphur	·02	·016	·03
Phosphorus	·49	·64	·55
Moisture	17·70	18·30	20·0

The Sheepbridge Co. use most of the output of their Cottesmore ore in their own furnaces, and regard it as a good ore in mixture for making forge-iron, but not for the production of steel. A small part of the output is sold.

The ore so far has been worked westward towards the outcrop, from the east end of the area now exhausted, and will continue for some time to be worked in that direction. Later, operations will be extended northward. In the area worked out, one small tract of bad ground was left untouched.

A small area immediately south of Cottesmore village, on the south-east side of the Sheepbridge Company's boundary, has been rejected, after trialing, as containing too much inferior stone; but south of this the ground has been leased nearly as far as Burley by Messrs. Bell Bros., Ltd.: work on this ground has, however, not yet begun.

The Northampton Ironstone has been proved of workable quality in the valley of the River Chater near Luffenham Station, and has recently been leased, but not yet worked, between South Luffenham and Wing.

At Manton it was being worked in 1887[3], but only for a short time, and more recently it was got for a time at Ridlington two or three miles farther south-west.

Messrs. James Pain, Ltd., are now getting this ore at Uppingham, on the south side of the town, in two pits, on each side of the road to Kettering. In the larger or Glebe pit on the west side, with a working-face 2,000 ft. in length, the cover, which consists entirely of blue Chalky Boulder-clay, with some large striated limestone-boulders, amounts to a maximum of 20 ft. or rather more, with an average of 15 ft. The ironstone varies in thickness from 7 ft. to 9 ft. or 10 ft., and is now worked mainly by steam-digger. The following section illustrates its character :—

Section in Glebe Pit, about middle of working-face.	Ft.	ins.
Blue Chalky Boulder-clay	—	
Brown rather hard somewhat sandy oolitic ironstone, more massive and in larger blocks than at the west end : no blue cores ; about	4	6
Massive rather sandy oolitic ironstone in two courses, for the most part of a dull light bluish green colour, in large blocks which are rejected as poor in iron ; but within it there is locally good weathered stone, where the jointing is close ; about	2	6
Brown thinner-bedded rather sandy oolitic ironstone, with some comparatively thin blue cores	2	0
Blue or green ferriferous sandstone : thickness not proved	—	
Total ironstone about	9	0

[1] From F. H. Hatch, *op. cit.*

[2] From the Ministry of Munitions.

[3] Home Office Records.

In the smaller Adderley Pit, with a working-face 600 ft. in length, east of the road, conditions are similar, but while the ironstone is said to average 8 ft., the cover averages only 10 ft. in thickness.

The following analyses show the composition of the ore at Uppingham :—

	I.[1]	II.[2] (Glebe)	III.[2] (Glebe)	IV.[2] (Adderley)	V.[2]
Iron	30·00	34·8	32·0	31·5	29·04
Iron (dried at 100° C.)	35·46	—	—	—	—
Silica	17·05	11·5	7·5	10·5	18·19
Alumina	7·00	—	—	—	—
Lime	3·42	2·8	2·5	2·5	3·28
Magnesia	·84	—	—	—	—
Manganese	·12	—	—	—	—
Sulphur	·08	—	—	—	—
Phosphorus	·59	—	·9	·9	—
Moisture	15·40	14·0	—	—	—

In the Uppingham workings the ore is being worked southward from the areas already exhausted, *i.e.*, away from the outcrop of the ironstone on the south flank of a valley running eastward on the south side of the town.

At Barrowden arrangements have recently (1918) been made for working the ironstone on the north-west side of the Welland valley. It is intended to work the ore by opencast, under a maximum cover of 40 ft. or a little more. Several trials on the high ground west and north-west of Barrowden have proved the ironstone at a maximum depth of 43 ft. or 44 ft.

A 'gullet' driven from the outcrop, on the south side of the road to Seaton, at a point three-quarters of a mile west of Barrowden Church showed the following section :—

	Ft.	ins.
Soil	1	6
Limestone (remnant) about	0	6
Lower Estuarine Series—		
Buff sand, at north end about	8	0
Blue clay : average about	2	6
Northampton Ironstone—		
Broken dirty ironstone mixed with sand, about	0	9
Brown oolitic ironstone, with some crystalline calcite in small crystals, and some 'box-structure' and cellular structure at outcrop	5	0

The ironstone is said to increase in thickness away from the outcrop. In this section there is some step-faulting, but not on a scale sufficient to break the continuity of the bed, and compensated by increased dip between the faults in a direction opposite to the downthrow, just as in the step-faulting at Wakerley (*see* below, p. 173).

The average of three analyses[3] of the Barrowden ironstone, at this gullet, at a trial-hole 190 yards south by west from it, and at another on the north side of the road 640 yards west of the gullet, was :—

Raw ore.	As received. per cent.	Dried at 100° C. per cent.
Iron	[35·75]	38·86
Silica	[8·32]	9·04
Lime	[7·10]	7·72
Manganese	[0·14]	0·15
Phosphorus	[0·57]	0·62
Moisture	8·0	—

[1] From F. H. Hatch, *op. cit.*
[2] From the Ministry of Munitions.
[3] From Mr. J. H. Keeble.

The less weathered Barrowden ore is said to be nearly self-fluxing. In that case the ironstone there must be much more calcareous than usual. The average silica-content as shown in the above analyses is decidedly low, and the lime-content of the three types of ore averaged ranges from 1·79 per cent. in the most weathered condition to 13·69 per cent. in the unweathered ore of the most westerly trial, where solid ironstone was proved at a depth of only 6 ft.

Local Details: Northamptonshire—Northern Part.

The Northampton Ironstone seems to have been worked intermittently on a small scale at Burleigh Park, on the south-east side of Stamford, from an early date. Outputs from there are recorded for 1859, 1866, and 1876.[1]

The same ore is now being worked by the North Lincolnshire Iron Co., for mixing with the Frodingham Ironstone, at Easton two miles south-west of Stamford. The ironstone there is unusually siliceous, some parts of the stone used containing as much as 40 per cent. of silica, a noteworthy contrast with the calcareous condition of the ironstone at Barrowden.

The cover averages 7 ft. in thickness, consisting of soil and subsoil of flaggy limestone above an even 4 ft. bed of buff loamy sand. The workable ironstone averages about 10 ft.; but owing to the necessity of rejecting the numerous 'sand-gulls' or infilled pockets and joints, and also excessively sandy parts of the ironstone, about one-third of the material raised (apart from cover) has to be picked out by hand. Consequently all work is necessarily done by hand-labour.

The upper part of the cover shows numerous isolated patches, partially disintegrated, of the flaggy basal beds of the Lincolnshire Limestone, outside the base-line of the limestone as drawn on the one-inch map (Old Series); and the workable ironstone itself extends considerably farther northward than is shown upon that map.

The ironstone is very variable not only from bed to bed but also in neighbouring parts of the same bed. Much of it is a brown ferruginous sandstone with brown ferric oxide filling the interstices between sand-grains, and is usually devoid of oolitic structure. Other parts are less sandy and decidedly oolitic, with a deposit of ferric oxide between the ooliths. The basal beds, of unproved thickness below the workable ironstone, consist of greenish-blue calcareous sandstone apparently containing little iron, but with a deposit of brown ferric oxide in joints and along bedding-places.

In the south face of the pit the top of the ironstone is perfectly flat and level. At the west end the thin-bedded ironstone underlies the sand in even layers without any discordance of bedding. But farther east, while the base of the sand remains horizontal, the bedding of the ironstone gradually bends down, more layers of ironstone coming in at the top with a gradually increasing eastward dip, so that the junction of sand and ironstone assumes an appearance of unconformability, which is, however, really due to current-bedding.

The upper part of the ironstone is regarded as rather less sandy than the lower. The following analysis shows the general composition of the Easton ironstone[2]:

	per cent.
Iron, as received	31·02
Iron, dried at 100° C.	35·47
Silica, as received	25·88
Alumina ,, ...	4·84
Lime ,, ...	1·30
Magnesia ,, ...	·63
Manganese ,, ...	·17
Sulphur ,, ...	·05
Phosphorus ,, ...	·52
Moisture	12·57

The directions of working are westward along the outcrop, and southward from its edge. The ground rises south-eastward for some distance. This rise might have been expected to denote the thickening of the overlying limestone,

[1] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

[2] From F. H. Hatch, 'Average Analyses of British Iron-Ores and Ironstones produced in 1917–18' (*Ministry of Munitions of War*), 1918.

but for a quarter of a mile southward the amount of cover is still only about 7 feet. At Wakerley a broad belt of step-faulting, which trends in the direction of Easton, produces a similar effect.

At Wakerley, on the south-east side of the Welland valley, the Partington Iron and Steel Co., Ltd., are working the Northampton Ironstone. So far the ore has been got only on the north-west or lower side of the road running south-westward from Wakerley village. In this working (the 'Old Cut') the ironstone is much broken, with numerous 'sand-gulls.' The following section represents the working-face of the 'Old Cut,' close to the road:—

	Ft.	Ins.		Ft.	Ins.
Soil	1	6	to	2	6
Lincolnshire Limestone (basal beds)—					
Flaggy limestone, much disturbed and disintegrated, variable in thickness, from ...	1	0	,,	3	6
Lower Estuarine Series—					
White, buff, ochreous and pale grey, very fine loamy sand, variable in thickness, from ...	7	0	,,	3	6
Northampton Ironstone—					
Brown not very sandy oolitic ironstone, with a good deal of ferric oxide along joint and bedding-planes as crusts, and also as interstitial matter: some soft cores show a more obviously sandy character: no green cores seen: thickness ...	6	0	,,	10	0

The general thickness of the ironstone ranges from 6 ft. to 10 ft. 6 ins. All work has so far been done by hand-labour.

The following analysis has been furnished by the Ministry of Munitions:—

Averaged analysis of the Partington Iron and Steel Co.'s Wakerley Ironstone.

Raw ore (dried ?).

	Per cent.
Iron	38·04
Silica	10·39
Alumina	4·14
Lime	3·16
Magnesia	·48
Manganese	·18
Sulphur	·083
Phosphorus	·635
Moisture [in moist stone ?]	12·11
Loss on calcination	14·42

The direction of working has been south towards the road from the outer edge; but work will no doubt be extended south-westward along the outcrop.

The Partington Company use the whole output of their Wakerley ironstone in their own blast-furnaces. No calcining is done at Wakerley.

Preparations have been made recently for extending the working south-eastward beyond the road, in which direction the ground rises; and a new cutting has laid bare the surface of the ironstone for a considerable distance in that direction. From the road, for a distance of 70 yards, numerous small faults traverse the ironstone in a general north-easterly direction at short intervals. They continue beyond that distance but are there less frequent, with wider intervals. They throw the ironstone down successively south-eastward, a few feet at a time; but as the strata in the intervening spaces are strongly tilted in the opposite direction, the net result is a steady rise to the south-eastward. Moreover, the Lower Estuarine beds between the ironstone and the Lincolnshire Limestone rapidly increase in thickness in that direction. At a point about 190 yards from the road the side of the cutting and a trial-hole sunk in the bottom of it gave the following section:—

Lincolnshire Limestone.—	Ft.	Ins.
Even-bedded flaggy limestone with slight dip to N.W., about...	4	6

	Ft.	Ins.
Passage Beds ?—		
Buff and white sand	2	6
Alternate even-bedded hard and compact pale grey calcareous sandstone, and buff sand: in the middle a 9-inch band of oolitic limestone, with small shells, including *Pecten*, and wood	3	9
Buff sand, with a large bullion of pale grey and blue hard calcareous sandstone, about	2	9
Thin- and even-bedded pale pinkish-grey, blue-hearted compact hard sandy limestone or calcareous sandstone, with bands of small lamellibranchs and a few casts of large lamellibranchs, about	1	3
Lower Estuarine Series.—		
Buff sand (in trial-hole), estimated	13	0
Northampton Ironstone.—		
Top of ironstone	—	
Total depth to ironstone	27	9

The unexpected increase of the beds between the ironstone and the typical Lincolnshire Limestone from a mean of about 5 ft. to fully 23 ft. in a distance of about 200 yards, and especially the incoming of the very hard calcareous sandstone may necessitate mining the ironstone instead of working it opencast as had been intended. In the meantime the development of the new working has been suspended.

In the new cutting, several hollows eroded in the beds above the ironstone are filled with tough boulder-clay.

West Side of Main Northampton Ore-field.

In an outlier several miles farther west, beyond the main outcrop of the ironstone, the Northampton ore was worked for a short time at Nevill Holt[1] as far back as 1864–5, and at Medbourne[1] in 1873–4.

Lloyd's Ironstone Company, Ltd., with blast-furnaces at Corby, have an important group of eleven pits or workings, which extend from Corby to Weldon and the neighbourhood of Rockingham. The positions of all these pits are indicated by the areas of worked-out ironstone on the map (Pl. VIII). Eight of the pits were working in 1917; the other three were closed. They are distinguished by name and position as follows:—

On west side of railway (from north to south):—Gretton; Rockingham; West Glebe (disused).

On east side of railway (from north to south):—Deene; Excellent; Old Glebe. Hunter's Close, and Hull's Well (these three continuous from west to east); Buildings Field (disused); Long Hills, S.W. of Weldon; Field 71 (disused), S.E. of Corby.

The thickness of cover and workable ironstone in these pits is:—

Name of Pit.	Cover. Ft.		Ironstone. Ft.
Gretton	9	.....	8
West Glebe	35	.....	12
Deene (Cardigan)	28	.....	9
Excellent	25–36	.....	9–10
Old Glebe	25–28	.....	8– 9
Hunter's Close and Hull's Well	8–16 (locally up to 30).		8– 9 (at east end of Hull's Well only 6 ft.).
Long Hills	25–30	.....	8
Field 71	9–12	.....	9

[1] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

In the Deene or Cardigan pit the general section of the beds is as follows :—

Lincolnshire Limestone (basal beds)—	
Flaggy limestone (thin)	
'*Collyweston Slate*'—	
Buff sand containing a bed of large calcareous bullions 6 ft. in length, which split into flags.	
Lower Estuarine Series—	About 28 ft.
Buff sand	
Black carbonaceous clay	
Pale grey very fine-grained silty sand	
Dark blue shaly clay	
Very fine-grained silty clay	
(Gap, obscured).	
Irregular and impersistent bed of hard pale-grey silty quartzitic sandstone with rootlets (practically a bastard ganister), passing by impregnation into a poor sandy ironstone, in irregular patches...	nil to 3 ft.
Northampton Ironstone—	
Oolitic ironstone, brown, with few green cores, variable in quantity, average thickness	8 ft.

The fissile bullions in the representative of the Collyweston Slate all split by weathering in place into perfectly regular flags, just as the continuous beds of the Collyweston Slate do. These bullions are present in the Deene pit only.

The ganister-like bed locally present at the top of the ironstone is rejected, except where highly impregnated with iron.

In the Excellent pit the cover consists of boulder-clay : the ironstone contains much brown-crusted green carbonate ore, rather calcareous.

In the old Glebe pit the ironstone is mostly green carbonate of which there is a greater proportion in this pit than in any of the others. It passes down rather gradually through a calcareous and ferriferous sandstone, of sage-green colour, which still contains ooliths, into a mere calcareous sandstone of the same colour with little iron, but some shells. The sandstone may be fully 15 ft. in thickness.

In Hull's Well pit there is comparatively little green carbonate stone. The ore diminishes at the east end to 6 ft. and the cover from 26 ft. to 8 ft.

In Long Hills pit the Lincolnshire Limestone, constituting the greater part of the cover, increases to 25 ft., and all but the lowest part is a massive oolitic limestone used in the Corby furnaces as a flux and regarded as the best fluxing limestone in the district. The basal part of it is disintegrated into a coarse oolite-sand. This is separated normally from the ironstone below by about 6 ft. of blue Estuarine clay, which, where present, shows sharp and even boundaries at top and bottom but has its interior bedding strongly wrinkled into undulations. In about 10 yards the whole clay-bed is gradually pinched out and disappears completely, so that the oolite-sand comes to rest directly upon the ironstone, and continues to do so for a considerable distance. Finally the Estuarine clay comes in again even more abruptly, the beds are at once tilted up strongly, and a fault throws them down several feet on the east side. The disappearance of the clay is clearly due to differential lateral movement, the limestone having slid over the ironstone and smeared out the clay.

In the Gretton, Excellent and Long Hills pits the direction of working is southward, in the others northward. In all these pits work has begun at the outcrop of the ironstone on the flanks of valleys trending roughly west and east.

The following are analyses[1] of the raw stone of Messrs. Lloyd's several pits:—

Name of Pit.	Gretton.		Deene.	Excel-lent.	West Glebe.	Hunter's Close and Hull's Well.	Long Hills.
	I.		II.	III.	IV.	V.	VI.
	(*a*)	(*b*)	percentage.				
Iron	32·64	33·86	33–34	33–34	32·84	33–40	33–34
Iron (dried at 100° C.) ...	40·70	41·0	—	—	—	—	—
Silica	8·74	10.07	0·8	0·8	11·43	8·0	8·0
Alumina	7·16	7·52	—	—	6·10	—	—
Lime	1·81	1·59	4·0	3·0	3·02	0·4	4·0
Magnesia	—	—	—	—	0·21	—	—
Manganese ...	—	—	—	—	0·11	—	—
Sulphur	—	—	—	—	0·166	—	—
Phosphorus ...	0·78	0·72	0·7	0·7	0·63	0·7	0·7
Moisture	19·8	17·4	—	—	19·11	—	—
Loss on calcination	—	—	—	—	10·30	—	—

All Messrs. Lloyd's pits are worked opencast, mostly by steam-navvy, which is always used for removing heavy cover from 10 ft. upwards in thickness. Only the green ore is calcined.

Much has been done by Messrs. Lloyd to prove the distribution of the ironstone under cover in the neighbourhood of Gretton Plain, *i.e.*, in the ground between their Gretton and Rockingham pits, and thence westward as far as Rockingham, as well as about half that distance eastward of the railway. This exploration by boring and sinking trial-holes has shown that under a level plain of boulder-clay the ironstone on the whole increases in depth from 8 or 9 ft. at the Gretton pit southward to a maximum of about 44 ft. half-way towards the Rockingham pit; that the workable ore generally has a thickness of 7–10 ft., but that about 100 yards south of the Gretton pit there exists a barren tract comparable in extent with the exhausted area of that pit, with another area of poor or no ironstone a quarter of a mile north-east from its east end and a larger barren area coinciding roughly with the northern half of Gretton Wood south-west of the same pit (*see* one-inch Ordnance map, sheet 171 New Series); also that westward from that wood the ore has a general thickness of 8 or 9 ft. at a depth varying between 25 ft. and 40 ft., except near the outcrop. In the barren areas above-mentioned the boulder-clay appears to rest directly on the Upper Lias.

Further explorations along a line south-eastward from the Corby furnaces proved the depth of the ironstone to vary between 25ft and 42 ft. and finally to decrease to 14 ft. between points one mile and one and a half miles distant from the furnaces. the thickness of ironstone varying in the same distance between 5 ft. 6 ins. and 10 ft. The beds have a general south-easterly dip towards the trough of the west-east syncline described above (p. 151). Half a mile farther east a well at the north end of Stanion village. one and three-quarter miles south-east of the Corby furnaces, proved 11 ft. of ironstone at a depth of 34 ft. 6 ins.[2]

At Snatchill one and three-quarter miles south-west of the Corby furnaces the ironstone was proved at a depth of 38 ft., with a heavy bed of limestone at the surface: but thence southward nearly as far as the Geddington workings the ore has not been found. presumably owing to its greater depth in the shallow syncline (*see* above, p. 151; also Pl. VII, Sect. 1).

Farther west, the ironstone seems to have been tried at Wilbarston on the edge of the main outcrop but not yet to have been worked.

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[1] No. I. from Lloyd's Ironstone Co., Ltd., the others from the Ministry of Munitions. Nos. II, III, V and VI give average values, and in the case of iron the range of variation.

[2] For this well-section *see* 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*), 1909, p. 152.

Mr. E. P. Davis (Bennerley Furnaces, Derbyshire) works the Northampton Ironstone by opencast west of Geddington, on the S. side of this synclinal trough. Several of the old pits are now closed : the two principal workings are both on the north side of the valley, No. 3 pit at the east end of the worked area, south of the road westward from Geddington, and No. 4 pit north of that road. The direction of working is eastward in both pits. Besides these a small area, known as the Turnip Field, is still being worked on the south side of the valley ; and is the second worked area westward from Geddington as shown on the map (Pl. VIII).

The cover attains a maximum thickness of about 20 ft. in Nos. 3 and 4 pits, much less in the Turnip Field. The thickness of ironstone is about 8 ft. in No. 3 ; 9 ft. 6 ins. to 10 ft. in No. 4 ; and about 5 ft. in the Turnip Field. In the rest of the ground remaining, but not now worked, on the south side of the valley, the ironstone is said to average 6 ft.

The following sections show the sequence of strata in the two larger pits now working :—

Section in No. 3 pit, at N.E. end.

	Thickness. Ft.	ins.
Lincolnshire Limestone—		
Soil and remnants of basal limestone, about	4	6
Lower Estuarine Series—		
Pale blue clay, up to about	1	6
Buff and white fine-grained sand and sand-rock, about ...	5	0
Northampton Ironstone—		
Bluish-grey, more or less oolitic and probably sandy limestone (' bastard stone ' rejected), up to...	1	6
Brown oolitic ironstone varying from darker to lighter colour, with some hard and massive beds in the middle and lower parts, some of these in the lower part being blue-hearted : not much ' box-structure ' ; but in some parts numerous horizontal laminæ of brown ferric oxide ... ... 8 ft. or	9	0

Section in No. 4 pit, at middle of east side.

Lincolnshire Limestone—		
Soil and disintegrated remnant of limestone ... nil to	3	0
Passage-beds ?—		
Yellow fine-grained sand, about	3	6
Irregular bands of alternate limestone and sand, about ...	1	0
Lower Estuarine Series—		
Yellow sand, coarser than that below ; reddish at bottom, about...	4	0
Black carbonaceous shaly clay, about	1	0
Very fine-grained pale-grey silt, with the texture of fuller's earth, about	0	6
Very fine-grained light brownish grey muddy silt, about...	1	6
Fine-grained buff and white silty sand, about	5	0
Northampton Ironstone—		
Hard massive somewhat calcareous brown oolitic ironstone, more or less blue-hearted : a shelly calcareous band in lower part, about...	4	0
Rather hard massive and thin-bedded brown densely oolitic ironstone, with a good deal of ' box-structure ' in upper and lower parts ; less in the harder and more massive middle part : in all parts the larger blocks are here and there blue-hearted	7	6

In No. 3 pit there are numerous small clay- and sand-' gulls ' coming down from above, and these appreciably diminish the average thickness of workable ironstone.

The middle part of the ironstone is regarded as generally best. Towards the bottom the stone becomes more siliceous and generally less calcareous, as it begins to pass down into the basal sandy beds, of which the thickness has not been proved here.

The following partial analyses[1] show the character of Mr. Davis's Geddington ironstone :—

	I.	II.	
	Raw ore, as received. per cent.	Raw ore, as received. per cent.	Calcined. per cent.
Iron	34	33	44·0
Silica	9	10	13·3
Alumina	6	6	8·0
Lime	5	8	10·0
Phosphorus	·5	·5	·66
Loss on calcination ...	—	25	—

In both the larger pits the cover is removed by steam-navvy, but the ironstone is worked by hand. In the Turnip Field both cover and ore were, at the time, being worked by hand. All the green stone and the large lumps of brown are calcined, the proportion of stone calcined being about half. The ironstone is sent direct to the Bennerley furnaces.

The Sheepbridge Coal and Iron Co., Ltd., work the Northampton Ironstone at Desborough, on the north side of the railway. Work is proceeding chiefly westward in the northern part and northward in the southern part of the present working area : but a farther extensive lease a little farther to the north-east has not yet been touched.

The cover, usually thick, ranges from 9 ft. to 26 ft., and the ironstone averages 9 ft., with worthless sandy stone below. The ore shows an unusually calcareous character for about 100 yards in the middle of the long working-face that trends north-east, where the following section was noted :—

	Thickness. Ft. ins.
Thin boulder-clay—	
Northampton Ironstone—	
Hard pale grey limestone, only slightly oolitic, with white ooliths, the matrix largely crystalline calcite, about ...	1 0
Hard calcareous, green-hearted, more oolitic stone, with crusts of brown f rric oxide—probably a poor ironstone—about	0 8
Greenish-grey dense hard ferriferous limestone, some parts not oolitic at all, but others more or less oolitic : crusts of brown ferric oxide along joint and bedding-planes	1 0
Brown oolitic ironstone, rather soft, with 'box-structure' of ferric oxide, about	6 0
(bottom of working-face).	

The abnormal and highly calcareous upper beds apparently thin out in both directions and give place to normal ironstone. The lower sandy beds below the working-face consist, as seen in drainage-trenches, of blue or green calcareous and ferriferous sandstone, of the usual type of the basal beds in the district. It is said that between this basal blue or green sandstone and the brown ironstone above, a white sandy bed is usually found just below the floor of the working : where seen at one point this white bed consisted of almost pure white quartzose sandstone, of quite unusual appearance in the Northampton Sand.

The cover consists mainly of boulder-clay, but in some parts of the 'face' a bed of white very fine-grained sand, about 9 ft. thick, and surmounted locally by a patch of pale-grey clay, both sand and clay belonging to the Lower Estuarine Series, overlies the ironstone.

Cover and ironstone are both worked by steam-digger. The local calcareous upper beds of the ironstone described above are not rejected in working the stone : the large lumps in which these hard beds are got by the steam-digger have to be broken by hand.

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[1] From the Ministry of Munitions.

The following are analyses of the Sheepbridge Company's Desborough ironstone :—

Raw ore, as received.	I.[1] per cent.	II.[2] (Average for Sept., 1917).	III.[3] per cent.
Iron	35·662	31·70	29·40
Iron (dried at 100° C.)	—	37·80	34·53
Silica	17·57	13·45	14.42
Alumina	5·931	—	6·20
Lime	·827	5·79	5·42
Magnesia	trace	—	·37
Manganese	·254	—	·20
Sulphur	·032	—	·04
Phosphorus	·318	·605	·49
Moisture	8·800	16·02	14·85

The Company's own furnaces at Sheepbridge consume about two-thirds of the output. Calcining has only recently been done at the quarries. The practice now is to calcine there any surplus worked above immediate requirements.

Between the south-west side of the Sheepbridge Company's ground and the railway the Kettering Iron and Coal Co., Ltd., have a small area of ironstone, not yet worked.

The Desborough Co-operative Society, Ltd., have worked out a small area of ironstone on the south-west side of Desborough. The old working-face there, which has practically reached the outcrop-edge of the ironstone along the north-west side of the area, shows the cover, consisting almost entirely of boulder-clay and gravelly drift, to vary in thickness from 2 ft. at the north end to 14 ft. farther south, and the ironstone, as last worked, to range from 4 ft. 6 ins. to 6 ft. 6 ins. exceptionally. The following is a section of the beds near the north end :—

	Ft.	Ins.
Soil and remnant of drift	2	6
Buff sand-rock and sand (local remnant of *Lower Estuarine Series*)	1	0
Northampton Ironstone—		
Rather light brown somewhat calcareous, but well-weathered, oolitic ironstone (in the top much small 'box-structure' of brown ferric oxide)	1	0
Deeper yellowish-brown oolitic ironstone, rather stronger, with much small cellular- and 'box-structure' and some shelly beds, about	3	6
Rich-looking weathered brown oolitic ironstone with still more small cellular- and 'box-structure'	0	4
Stronger yellowish-brown oolitic ironstone, probably rather sandy, with less 'box-structure'...	1	0

The Co-operative Society are now working another area extending from Thorpe Underwood, one and a quarter miles west of Rothwell south-westward towards Harrington, and divided into three separate workings. In these the direction of working is south-eastward from the outcrop-edge. Except in the most northerly of the three, in which a small remnant of ore is worked towards its outer edge on the north-west side.

The thickness of cover in these workings varies from *nil* to 8 or 9 ft. The working-thickness of ironstone averages 6 ft., but this stone passes down into stone of inferior quality, very calcareous as well as sandy, of which there is probably another 6 ft. below the floor of the workings. The section in the middle of the Harrington pit, the most south-westerly, showed :—

	Ft.	ins.
Soil ... ... 3 ft. to	1	0
Lower Estuarine Series—		
White sand ... ... 1 ft. to	3	0
Yellow sand, about	0	8

[1] From the Ministry of Munitions.

[2] From the Sheepbridge Coal and Iron Co., Ltd.

[3] From F. H. Hatch, 'Average Analyses of British Iron-ores and Ironstones produced in 1917–18' (Ministry of Munitions of War), 1918.

Northampton Ironstone—	Ft.	ins.
Brown sandy ironstone (rejected) ... ... 4 ins. to	0	8
Rather thin-bedded, close-jointed brown oolitic ironstone, said to contain 34 per cent. of iron, with much 'box-structure,' about	6	0
Inferior sandy and calcareous ironstone (not seen), said to contain not more than 20 per cent. of iron	—	

There are no unweathered green beds.

At a small fault, which throws down the ironstone two or three feet on its north side, and throws out the estuarine sand on the other side, the ironstone is said to be workable down to the same level on both sides. This of course suggests redistribution of iron in the weathering stone subsequently to the faulting.

The following analyses represent the chemical composition of the Desborough Co-operative Society's ironstone at their Thorpe Underwood and Desborough pits:—

Raw ore, as received.	I.[1] Thorpe Underwood Pit. per cent.	II.[2] Desborough Pit. per cent.
Iron	32·70	34·59
Iron (dried at 100° C.)	37·80	[41·39]
Silica	15·15	11·20
Alumina	7·79	7·59
Lime	3·59	10·20
Magnesia	·16	1·16
Manganese	·09	·02
Sulphur	·073	·26
Phosphorus	·59	—
Moisture	18·79	16·43
Loss on ignition	11·46	18·00

All working is opencast, by hand-labour. In the Harrington and Thorpe Underwood pits, where locally the upper part of the ironstone is disintegrated and has passed into the cover, good ore is saved from the cover by shaking out with the fork. All the ore is sold.

The Stanton Ironworks Company's Rothwell Hill quarries are situated on the north-west side of Rothwell, almost in continuation of the line of the Desborough Co-operative Society's Thorpe Underwood workings. The Stanton Company's two pits are separated only by the road from Rothwell to Desborough and are distinguished as the Long pit, with a working-face 3,900 ft. in length, on the south side of the road, and the Little pit, with a working-face of 1,500 ft., on the north side. The direction of working is south-eastward, away from the outcrop-edge.

The cover, consisting in both pits entirely of boulder-clay (which contains large tabular mottled grey flints, some of them striated) ranges in thickness from 26 ft. down to 15 ft., with an average of 19 or 20 ft. in the Long pit; while throughout the greater part of the Little pit it varies between 3 ft. and 9 ft., but increases to 20 ft. at the south-west end. The average thickness of workable ironstone in the Rothwell Hill pits is about 9 ft., with 6 ft.—12 ft. of worthless sandy stone below. In the Long pit the ore is practically all weathered brown, with no trace of blue cores, except here and there at the bottom of the working. It is densely oolitic, and on the whole rather hard, massive, and sharp-jointed with abundant 'box-structure,' but not in the final stage of small crusts enclosing little rounded and bleached cores. In the Little pit the ironstone maintains the same character at the south-west end. But north-eastward, on approaching its outcrop, it becomes less hard and much less clean in appearance, some of the joints being faced with clay from the cover, while a few widened joints become regular 'clay-gulls,' which must be rejected. In the same direction the lowest beds worked become somewhat sandy, while some of the higher beds are distinctly calcareous. The Rothwell Hill ironstone is expected to yield 33–34 per cent. of iron (raw stone, moist). The lime-content is said to vary between

[1] From the Ministry of Munitions.

[2] From the Desborough Co-operative Society Ltd.

2 and 7 per cent. in the Long pit, and between 3 and 7·4 per cent. in the Little pit. The following is a partial analysis[1] of the raw ore :—

	Per cent.
Iron	37·0
Silica	17·0
Lime	5·0
Phosphorus	·7

One steam-navvy is employed for boring the ironstone in the Long Pit : all other work is done by hand. There is no treatment of the ore at the pit. The Stanton Company ordinarily use all their ore from these pits in their own furnaces ; but occasionally they sell a little of it. Some part of the ore is calcined in kilns at Stanton.

The next workings eastward, known as Rothwell Deep and Rothwell Shallow pits, more than half a mile east of Rothwell, belong to Messrs. James Pain, Ltd., who have an important group of workings extending thence north-eastward and eastward in the directions of Geddington and Weekley.

In the Rothwell Shallow pit, including the northern part of the worked area indicated on the map (Pl. VIII) and separated from the Deep pit on the south merely by the road from Weekley to Rothwell, the cover consists of 1–3 ft. of soil, and the ironstone, a well-weathered brown oolitic ore, averages 7 ft. in thickness. All work is done by steam-navvy.

In the Deep pit the cover consists of Chalky Boulder-clay, varying from 12 ft. to 18 ft. The ironstone has a thickness of 12 ft. and, except the bottom bed, which is hard and calcareous, with a little blue-hearted stone, all the ore consists of soft brown oolitic ironstone, mostly thin-bedded, with much interlaminated brown oxide as well as small cellular structure. Both cover and ironstone are worked by hand, as the soft stone is easily got with pick and shovel : but the hard bed at the bottom is blasted.

The road separating the two pits runs along a broad ridge bounded by valleys north and south, so that the ironstone crops out in both directions. The direction of working is from the road towards the outer edge, northward in the Shallow and southward in the Deep pit.

The length of working-face is 1,350 ft. in the Deep and 900 ft. in the Shallow pit. Partial analyses[2] of the raw ore are as follows :—

	Rothwell Shallow pit. I. per cent.	Rothwell Deep pit. II. per cent.
Iron	32·2	31·5
Silica	11·0	10·5
Lime	1·5	2·0
Phosphorus	1·2	1·0

The other workings belonging to Messrs. Pain in this neighbourhood and known collectively as their Kettering, Glendon or Weekley pits, form a group extending from the Ise valley on the north to the tributary valley of the Slade and the northern outskirts of Kettering. Of these, the pits on the west side of the railway to Market Harborough have been worked out and abandoned ; but a smaller area (Knobby's Hole) remains incompletely worked in the angle between the two branches of the railway. Adjacent to the railway on its east side are the Glendon Shallow (northern) and Cherry Hall (southern) pits, the former adjoining the most westerly of the Geddington workings. The area intervening between the Glendon Shallow and Cherry Hall pits is now being worked north-eastward from the latter. Eastward of the Cherry Hall pit and separated from it by the road northward from Kettering to Rockingham are the Bridge, Wood Lane, and Boughton pits, the last-named south of the road to Weekley, with a large area worked out on its south side. The pits working in 1917 were the Boughton, Wood Lane, Bridge and Cherry Hall pits ; also Glendon Shallow, with a small output, work in this pit being almost finished.

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[1] From the Ministry of Munitions. [2] *Id.*

The details of cover, ironstone and length of working-face in the several pits are as follows:—[1]

Name of Pit.	Length of face in feet.	Thickness of cover. ft.	Thickness of ironstone. ft.
Knobby's Hole	900	20	10
Glendon Shallow, about	700	3	6
Cherry Hall	6,900	25	13
Bridge	500	20	13
Wood Lane	600	15	9
Boughton	4,620	18	13

The following sections were noted:—

Cherry Hall Pit, about middle of working-face.

	Ft.	ins.
Lincolnshire Limestone—		
Cream-coloured more or less oolitic limestone ... up to	3	0
Lower Estuarine Series—		
Pale brownish-grey silty sand	1	6
Dark grey shale ... ... about	4	0
Lighter grey very fine micaceous silt	2	6
Obscured ... ... about	6	0
Northampton Ironstone—		
Massive brown oolitic ironstone, with scarcely any green cores except near bottom: much 'box-structure' especially in upper part: lime-deposit on joints: some cross-bedding: lowest beds apparently rather sandy: thickness ... ... 9 ft 6 ins. to	13	0

Boughton Pit, at footbridge.

	Ft.	ins.
Soil ... ... about	2	0
Lower Estuarine Series—		
Pale purplish-grey shaly clay ... ... about	2	0
Fine white silty sand ... ... about	6	0
Northampton Ironstone—		
Variable hard and soft brown ironstone, strongly oolitic where less weathered, with much 'box-structure' of brown ferric oxide in joints and particularly in close horizontal laminae: in lower part some blue cores in thin beds: seen ... ... 9 ft. to	9	

The following analyses[2] represent the character of the raw ironstone in the several pits:—

Name of Pit.	Knobby's Hole. I.	Glendon Shallow. II.	Cherry Hall. III.	Bridge. IV.	Wood Lane. V.	Boughton. VI.
Iron	31·5	36·45	32·0	32·0	33·2	32·5
Iron (dried at 100° C.) ...	—	40·93	—	—	—	—
Silica	9·0	14·20	9·0	10·5	10·5	10·5
Alumina ...	—	7·02	—	—	—	—
Lime	2·5	·94	2·5	1·0	2·0	1·0
Magnesia ...	—	·49	—	—	—	—
Manganese ...	—	·24	—	—	—	—
Sulphur... ...	—	·027	—	—	—	—
Phosphorus ...	·95	·659	·95	·85	1·4	·9
Moisture ...	—	10·94	—	—	—	—

[1] From the Ministry of Munitions. [2] *Id.*

Work is done largely by steam-navvy. The ore is not calcined at the pits. The whole output is sold.

Three or more borings carried out by Messrs. Pain in Weekley Hall Wood, in the angle between their most easterly workings on the south and the Geddington pits on the north, proved the ironstone at considerably greater depth than in the neighbouring opencast workings.

East Side of Main Northampton ore-field.

On the east side of the ironfield the nearest workings to Messrs. Lloyd's at Corby and Weldon are those of the Islip Iron Co., Ltd., at Sudborough and Lowick. No ironstone has as yet been worked in the intervening ground either on that side or in the interior of the ore-field, where the ironstone rarely reaches the surface, and in the synclinal part of the field (*see* p. 151) must lie at considerable depth. The ironstone has not been proved between the village of Stanion and Brigstock two miles east-south-east of it; and in that distance the strata may be expected to traverse the trough of the west-east syncline (Pl. VII, Sect. 1).

The section of a bore-hole near Farming Wood Hall[1] about 1¾ miles north-east of Brigstock, somewhat farther eastward than any outcrop of the ironstone in that part of the district, shows 7 feet of brown stone at a depth of 159 feet. This is regarded, no doubt rightly, as the Northampton Ironstone. The boring probably passed through a fault, which cuts out the greater part of the Great Oolite and Upper Estuarine Series.

Workable ironstone has been proved by Messrs. Lloyd at intervals throughout the distance between Brigstock and Sudborough, and good-looking ore crops out in the stream-valley 1¼ miles due south of Brigstock church.

The Islip Iron Company's most northerly working is Lowick Glebe pit, immediately south-east of Sudborough and on the west side of the stream-valley. Their workings extend southward from Sudborough beyond Islip to the Kettering and Huntingdon Railway; they include the following opencast pits and underground mines:—

Names of workings.	Method of working.	Situation.
Lowick Glebe ...	Opencast...	Immediately south-east of Sudborough, on west side of valley.
Marsh's	„	¾ mile N.W. of Islip village.
Slipton Mines:—		
1. Woodfield ...	Mine ...	1¼ miles W.S.W. of Lowick: (Shaft:—Lat. 52° 24′ 10″ N.; Long. 0° 36′ 5″ W.)
2. Willowclose ...	„ ...	2 miles W.S.W. of Lowick: (Shaft:—Lat. 52° 24′ 10″ N.; Long. 0° 36′ 25″ W.)
Church Mine ...	„ ...	½ mile N.W. of the furnaces: (Shaft:—Lat. 52° 23′ 35″ N.; Long. 0° 34′ 55″ W.)
Twywell	Opencast...	1 mile W. of furnaces.

The Islip Company's furnaces are situated on the north side of the railway one mile westward of Islip.

In the Company's most northerly working, Lowick Glebe, the cover, practically absent at the south-east end, increases to 45 feet in the north-west part, and is generally thick in the greater part of the working, as it is in the Marsh's pit farther south, but not in the Twywell pit, situated in the valley farther west. It consists at the Lowick Glebe pit of Great Oolite Limestone at the top, with Lower Estuarine sands and clays below, and reaches the maximum thickness of cover removed in opencast working in this district. The limestone is used for fluxing in the Islip furnaces. The beds have a perceptible eastward dip.

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[1] *See* 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*), 1909, p. 79, where a tentative classification of the strata passed through is given. An independent version of this boring obtained in the district and agreeing in all essentials with the published version, describes the 7 feet of brown stone as ferruginous.

Trial-holes along the south margin of the field immediately north of the pit proved the ironstone at depths varying from 40 feet to 45 feet. But a few yards further north in the same field (without any appreciable change of surface-level) the depth of the stone increases to 70—75 feet, and an east-and-west fault, throwing doing north, seems to intervene between the two positions.

The ironstone in the Lowick Glebe workings is for the most part brown and yellowish-brown, but several of the larger blocks in the lower half are bluish-green with only a thin crust of brown oxidized stone. It is densely oolitic, rather thick-bedded and massive, with 'box-structure' on a large scale. The lowest beds worked are not visibly sandy. The thickness in the middle of the northern face is about 13 feet 6 inches, a greater thickness than usual in the Islip Company's workings. In their opencast pits the workable ironstone is generally about 9 feet 6 inches or 10 feet thick: in the mines as a rule about 8 feet 6 inches is worked, the difference being due to the necessity of leaving the top bed to make a roof.

In a shaft sunk to the ironstone a quarter of a mile north-east of the furnaces and known as the Peray-hole shaft the workable ironstone was found to have a complete thickness of 7 ft. 6 ins.—a less thickness than anywhere else in the Company's workings—at a depth of 38 ft. 6 ins., the uppermost 18 ft. consisting of broken and thin-bedded limestone (Great Oolite). The ironstone is not worked from this shaft. Soft blue ironstone below the above thickness of harder ore contained only 33·5 per cent. of iron in the dried stone (*cf.* analysis of the main stone on p. 185).

In the Woodfield shaft the top of the ironstone lies at a depth of 90 ft. 8 ins. and at 207 O.D. There is 32 ft. 5 ins. of boulder-clay at the top of the shaft, above Great Oolite Limestone. (*See* Pl. VII, Section 2.)

A cutting close to the adit of the Willowclose mine shows the following sequence:—

	Ft.	ins.
Limestone (? *Estuarine*), up to	2	0
Calcareous marl with oyster-bed ... ... 2 ft. to	3	6
Lower Estuarine Series—		
Very fine-grained buff marly sand, about	9	0
Brown carbonaceous very fine-grained sandy clay, up to	5	0
White and pale grey very fine-grained silty sand, becoming almost an impalpable siliceous mud in parts, about ...	10	0
Strong blue clay	1	0
Northampton Ironstone—		
Ironstone	—	

The ironstone bed in this mine is subdivided as follows:—

Top bed (left in as roof)—		
Hard brown decalcified oolitic ironstone, with a shell-bed (which contains a small ribbed *Trigonia*), all the shells being represented merely by casts and moulds: thickness 9 ins. to 2 ft.; average	1	6
Middle bed—		
Hard deep greenish-blue densely oolitic ironstone, with occasional partings of brown oxide in bedding-planes and joints, about	2	6
Hard grey dense and compact carbonate-ironstone, much of it devoid of ooliths, about	1	0
Hard deep greenish-blue densely oolitic ironstone, as above: about	3	0
Lower bed—		
Soft and friable deep greenish-blue densely oolitic ironstone rarely in some of the other workings up to 5 ft.: here at least	2	0
Basal sandy bed (not worked)—		
Inferior greyish-blue sandy ironstone	—	

A similar subdivision applies to the ironstone in the Islip Company's other mines.

The strata at the Willowclose and Woodfield mines have a general eastward dip amounting to about 1 in 100 in the former mine and 1 in 29 in the latter.

At the shaft of the Church mine farther south, where the top of the ironstone lies at 157 O.D., the beds on the north side dip at first north and then change to a southerly dip, so that the workings there traverse an east-west syncline.

In the Company's opencast workings work is done for the most part, if not entirely, by hand. In underground mining the stone is got by hand, after blasting some part of it. The method of mining the stone is to work out the soft bottom bed first, and for this a somewhat greater thickness than 2 ft. is preferred in that bed, then to blast the rest of the stone. So far, the roof-bed has not been recovered, except where it has fallen.

In the Woodfield mine the direction of mining has been eastward from the adit, and the area worked amounts to about 21 acres, but so far about half has been left in as pillars. In the Willowclose mine the direction of working is almost due west: not much ground there has been completely worked out, but a good deal has been opened up in the course of ten years' work. The Church mine works due north.

Altogether the amount of ore so far raised from these mines amounts to about three-quarters of a million tons.

The following analyses[1], of which all but the last are average bulk-analyses representing a large amount of ore, show the chemical composition of the Islip Company's raw ore:—

	Lowick Glebe Quarry. (dried ore.) per cent.	Twywell Quarry. (dried ore.) per cent.	Woodfield Mine. (dried ore.) per cent.	Peray-hole Shaft. 7 ft. 6 ins. (dried ore.) per cent.
Iron (in moist ore)	33·04	37·92	30·74	—
Iron, dried at 100° C.	39·40	43·40	36·30	34·70
Silica, do.	18·05	11·90	9·60	11·30
Alumina, do.	6·10	5·80	7·08	6·57
Lime, do.	2·35	3·00	7·35	4·50
Magnesia, do.	·648	·564	1·314	1·53
Manganese oxide, dried at 100° C.	·558	·419	·316	·09
Sulphur do.	·057	·169	·458	·39
Phosphorus, do.	·784	·693	·821	·74
Average moisture (in moist ore)	16·13	13·56	15·28	—

Trials carried out by the Islip Co. on the ground over which they have the option of working, showed that the ore becomes too poor and siliceous for use under existing conditions, eastward of a line running north-eastward a short distance east of their furnaces nearly to Islip, and thence northward to Lowick, as shown approximately by the stipple on the map (Pl. VIII). Yet the ore was formerly mined at Woodford, to an uncertain extent east of this line; and good ore is found at Denford, still farther east, where it is leased, though not yet worked, by the Ebbw Vale Co., and at Ringstead,[2] where it was formerly worked for several years from 1872.

The Islip Co. smelt all their ore in their own furnaces. They have until recently been making a fluid foundry-iron and some forge-iron entirely from their Northampton Ironstone; but during the war they have turned out some basic pig for steel-production, after adding manganese-ore and some calcareous Marlstone ore.

A small area at Twywell, west of Islip, between the Twywell and Slipton workings of the Islip Co., is worked by Mr. F. Young, opencast, with one working-face 500 ft. in length. The thickness of cover ranges from nil to 27 ft., and the

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[1] From the Islip Iron Co.

[2] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*), and Home Office Records.

ironstone averages 10 ft. The output is sold in the calcined state. The following is an analysis[1] of the calcined ore:—

Calcined ore, as received.

	per cent.
Iron	44·27
Silica	13·3
Alumina	7·53
Lime	4·70
Phosphorus	·87
Loss in calcination	4·50
Moisture	1·18

Central part of Main Northampton ore-field.

The Cranford Ironstone Company, owned jointly by the Staveley Coal and Iron Co., Ltd., and Messrs. James Oakes & Co., Ltd. (Alfreton), work the Northampton Ironstone south-east and east of Cranford, on both sides of the railway.

The working-area north of the railway is divided into three 'faces,' corresponding to the three branches of the worked area as shown on the map. These are, from north-east to south-west:—(1) Jack Spinney; (2) Eleven Acre; (3) Old Duke's; the directions of working being north-westward in (1), north-eastward in (2), and northward in (3). The principal working-area of these at the present time is the Eleven-acre 'face' in which the cover ranges generally from 3 ft. to 22 ft., and exceptionally to 32 ft. in one part, the ironstone having a thickness of 8—10 ft., with 5 ft. of sandy stone below, which, where exposed, has a bright orange-brown colour, with pale-green cores. The ironstone is similar to that of the Glebe 'face' (*see* below), but thinner-bedded, with closer 'box-structure' and cellular weathering, the upper part being rather calcareous. In the middle of this face is a striking example of the kind of sharp anticline noted at Market Overton (*see* p. 169) and elsewhere, as producing a 'clay-gull' from below. The structure has evidently been produced along a line of weakness by lateral movement, in beds otherwise level, with little evidence of movement. In this case the beds rise suddenly into a sharp anticline, with dips of about 45°, so as to bring the top of the Upper Lias clay to the surface of the ground, on which the fold produces a very slight ridge trending north-east. In section, the fold flattens out rapidly to the south-east, and diminishes to a gentle dip towards the north-west. In the core of the fold the highest beds of the Upper Lias clay are arched into a sharp simple saddle. This passes downward into a blunter complex fold in which the clay is puckered into many wrinkles.

In the same Company's Glebe pit south of the railway, where the direction of working is southward and westward, the cover, amounting to 30 feet, consists of sands and clays of the combined Upper and Lower Estuarine Series, with an oyster-bed in the Upper Series. The ironstone, 10 feet—12 feet thick, is nearly all brown and oxidized, with very few green cores in the lower part. It is oolitic, fairly hard, and in rather massive beds, with more or less 'box-structure.' The middle beds are considered the best, the upper part being more calcareous and the lower distinctly sandy. Below the worked ironstone is about 2 feet 6 inches of 'bastard' or green sandy stone, resting on Upper Lias clay.

Several 'clay-gulls,' or pockets of clay let down along widened joints and small faults, have to be rejected. They are sufficiently numerous to diminish appreciably the output of the pit.

All working in the Cranford Company's pits is opencast, and done entirely by hand-labour. There is no treatment of the ore at the pit, beyond picking out 'clay-gulls.' All the green stone and the worse parts of the red stone are calcined in heaps or 'clamps.' The whole output goes to the Staveley Co.'s and Messrs. Oakes's furnaces. The following are analyses[2] of the Cranford Company's raw ore:—

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[1] From the Ministry of Munitions.

[2] *Id.*

Ore as received.	I. Per cent.		II. Per cent.		III. Per cent.
Iron	34·73	.....	33·83	.....	34·09
Iron (dried at 100° C) ...	—	.....	—	.....	41·10
Silica	19·29	.....	12·07	.....	17·13
Alumina	5·78	.....	3·46	.....	4·71
Lime	2·38	.....	1·16	.....	1·19
Magnesia	·33	.....	·65	.....	·10
Manganese ...	·19	(MnO)	·13	.....	—
Sulphur	·15	.....	·09	.....	·091
Phosphorus ...	·42	.....	·43	.....	·51
Moisture	8·11	.....	17·10	.....	16·84
Loss on ignition ...	14·33	.....	—	.....	10·37

The Clay Cross Company, Ltd., work the same ore on the west side of Cranford, now exclusively north of the valley and the railway. A considerable area has been worked out by mining south of the railway, but this area was abandoned four or five years ago.

The surface-stone has also been got on the north side, where the stone is now mined exclusively from the outcrop. The cover increases from 45 feet at a distance of 360 yards from the mine entrance, along the main road, and consists there of sand with some clay, the lowest member being sand, which increases the difficulty of mining. The limestone above comes in a little further on as the cover increases. The thickness of ironstone mined averages 7 feet, but varies considerably. In addition to the stone extracted, a minimum thickness—3 inches—1 foot— is left in to strengthen the roof. About 4 feet of 'bastard' sandy stone below is also left in the floor. The ironstone of the mine now worked is regarded as poorer in lime and higher in silica than that of the mine now disused on the south side of the railway.

There is no treatment of the ore at the pit. The green ore is calcined. Some calcined stone is sold and goes to Staffordshire, but the rest of the calcined and all the raw ore are used by the Clay Cross Company in their own furnaces. The ore now worked, as being siliceous and poor in lime, is mixed with more calcareous Northampton ore.

The following are partial analyses of the Clay Cross Co.'s Cranford raw ore:—

Ore, as received.	I.[1] Per cent.		II.[2] Per cent.
Iron	25·52	.....	31·07
Iron (dried at 100° C.) ...	29	.....	35·10
Silica	23	.....	24·35
Lime	2	.....	2·20
Moisture	12	.....	11·50

The ground on the north side of the railway westward as far as Barton Seagrave and northward of that place as far as Kettering has been rather fully tested by borings and trial-holes,[3] which have proved a somewhat sporadic development of workable ironstone, of the distribution of which a generalized representation is given on the map (Pl. VIII). The most northerly of the bore-holes, 1 mile N.W. of Cranford, passed through the Great Oolite Limestone series and proved 51 feet of cover without reaching the ironstone, while another 1½ miles W. 17 N. from Cranford similarly failed to reach the ironstone at 55 ft., so that in that part the ore would presumably require mining underground. Where the surface falls westward of the latter position, about three-fifths of a mile north of Barton Seagrave, three trial-holes proved a thickness of 4—5 feet of ironstone at its outcrop, with an iron-percentage ranging from about 35 to 38

[1] From the Ministry of Munitions.

[2] From F. H. Hatch. 'Average Analyses of British Iron-ores and Ironstones produced in 1917–18.' (*Ministry of Munitions of War*), 1918.

[3] Details of these explorations were communicated by Lloyd's Ironstone Co., Ltd.

in the moist raw stone, while eastward of the high ground several other trials found good brown ironstone, 7 to 8 feet thick, at depths ranging from 10 feet to 29 feet at a general distance of about three-quarters of a mile, and in a mean direction roughly north-west from Cranford. On the whole then, the available evidence is in favour of the persistence of good stone under the northern part of the ground tested.

Farther south, about the latitudes of Cranford and Barton Seagrave, where the surface sinks towards the railway, the distribution of good ironstone becomes irregular, rather as a result of erosion than of deterioration of the ironstone; but here and there (*e.g.*, three-fifths of a mile east of Barton Seagrave, where ironstone 5½ feet thick, under 15½ feet of cover was proved to contain only 11 per cent. of iron with nearly 46 per cent. of silica) the ore does seem to have deteriorated. The case, however, is not conclusive, for the cover, of which the nature is not recorded, may consist of drift overlying merely the sandy lower part of the ironstone-bed. Where good ore was proved in the southern part of the area tested, the iron-content ranges from about 30 per cent. to more than 40 per cent., in the moist raw stone. On the other hand, ironstone 11⅓ feet thick, three-quarters of a mile west of Barton Seagrave, is described as worthless, as is the outcrop-stone, 12 feet thick, the same distance south-west of that village. The maximum thickness of good ore in the whole area appears to be 9 feet, but the minimum full thickness is uncertain.

The Kettering Iron and Coal Co., Ltd., with their furnaces on the north-west side of Kettering, have an important series of opencast workings on the west and north-west sides of Kettering, west of the railway. These workings are separated by the Slade valley on the north from Messrs. Pain's pits, and extend westward slightly beyond Thorpe Malsor. Their pits are:—

Name of Pit.	Position and direction of working.	Thickness of cover.	Thickness of ironstone.
		Ft.	Ft.
1. 'Booth 3' ...	Working respectively westward and eastward from the exhausted area indicated west of the furnaces.	10	8
2. 'Booth 4' ...		1	3
3. 'Kettering Glebe'	Working southward from the small exhausted area one mile due west from the middle of Kettering.	4	6
4. 'Dalkeith' ...	Working eastward on the south-west side of Kettering, near the railway.	Ore very much broken: all material treated as cover and riddled out.	
5. 'Capt. Mansell'...	Working south-westward, one mile due west of the furnaces.	1	6
6. 'Coles'	Working eastward, two miles due west of the furnaces.	6[1]	5
7. 'Thorpe Glebe'...	Both working westward, on the west side of Thorpe Malsor: separated by the road to Loddington, 'Thorpe Glebe' being on the north side, and 'Mansell 4' on the south.	4	6
8. 'Mansell 4' ...		5	6

The ore being used in 1917 was obtained from the five pits known as 'Booth 3 and 4,' 'Kettering Glebe,' 'Captain Mansell,' and 'Coles.'

[1] There is not much more than 6 in. of soil and no drift nor Estuarine sand or clay above the ironstone in the present working-face (1917). Such cover as there is consists of broken ironstone-rubble under thin sandy soil, some ore being evidently saved from the cover by riddling. About 2 feet of lower sandy stone was seen below the worked ironstone.

The following are partial analyses[1] of the Kettering Co.'s raw ironstone :—

Name of pit	Booth 3.		Booth 4.	Kettering Glebe.	Dalkeith.
Ore dried at 100° C.	I. (Siliceous)	II. (Limy)	III. (Siliceous)	IV. (Siliceous)	V. (Siliceous)
Iron	42·2	35·60	48·55	40·20	37·60
Silica	10·46	10·69	7·94	15·92	17·52
Alumina	10·42	8·72	4·98	11·62	11·19
Lime	2·91	10·52	1·70	1·40	·76
Phosphorus	—	—	—	—	·67
Moisture (in moist stone)	6·30	8·50	14·60	13·50	14·40

Name of pit ...	Coles.		Thorpe Glebe.	Mansell 4.	
	VI. (Siliceous)	VII. (Limy)	VIII. (Limy)	IX. (Siliceous)	X. (Limy)
Iron	36·20	25·88	37·2	40·7	34·1
Silica	11·14	5·29	10·5	12·7	9·6
Alumina	7·31	5·64	10·6	7·5	3·5
Lime	9·26	26·54	12·2	2·3	13·4
Moisture (in moist stone)	15·45	9·3	5·1	12·1	8·2

Though the Kettering Company's ironstone in their normal workings carries little cover on the whole, and no great thickness in any of their pits, so that the ore is for the most part in a well weathered condition, yet the average percentage of lime is somewhat higher than elsewhere in the district, except perhaps at Brixworth and Barrowden, and in some of their workings the lime-content of the ore, or of some parts of it, reaches a remarkably high figure. At the same time the silica percentage is unusually low, while that of iron is normal. Consequently the ironstone of this part of the district must have been exceptionally calcareous in its unweathered state, with a low percentage of silica.

This highly calcareous condition does not continue northward into Messrs. Pain's Glendon and Rothwell pits. It seems to be most strongly pronounced on the west side of the Kettering Company's area : and may have continued to the north side of Desborough, where the Sheepbridge Company's pit shows a small local development of excessively calcareous stone (*see* p. 178). In the almost intermediate workings at Rothwell Hill the lime-content of the ore is rather greater than usual, and is said to increase northward.

In the Kettering Company's pits all work is done by hand-labour. Some of the ironstone is calcined at the works in heaps. The Company use in their furnaces only their own ore as a rule. Its unusually high percentage of lime is not enough to make their average ore self-fluxing.

Westward of the Kettering Company's Thorpe Malsor pits, the Loddington Ironstone Company have their workings on the west and south-west sides of Loddington village. The more northerly is known as the Orton, the more southerly as the Loddington pit. Work is now proceeding westward from the west ends of the two larger exhausted areas. The Company also have a small disused pit half a mile south of the village.

The thickness of cover ranges from 7 feet to 23 feet in the two working-pits, with an average of 15—17 feet. The ironstone averages 5 or 6 feet, with unworkable sandy stone of unproved thickness below.

The ironstone, of the usual oolitic character, largely weathered brown but partly green, is somewhat more calcareous than the average ore of the district, though considerably less calcareous than that of the neighbouring pits of the Kettering Co., and more siliceous. The cover is removed by steam-navvy, but the ironstone is worked by hand. There is no treatment of the ore at the pits, all parts of it being loaded together, and no calcining is done there.

[1] From the Ministry of Munitions; except No. V, supplied by the Kettering Iron and Coal Co.

The following analyses show the composition of the Loddington Company's raw ironstone :—

Ore as received.	I.[1] Per cent.	II.[1] Per cent.	III.[2] Per cent.
Iron	30·70	30·52	31·78
Iron (dried at 100° C.)	37·08	37·40	37·87
Silica	13·74	15·51	12·86
Alumina	3·70	5·01	5·23
Lime	5·04	4·32	3·91
Magnesia	·59	·06	·06
Manganese	·09	—	·09
Sulphur	·19	·12	·08
Phosphorus	·43	·56	·58
Moisture	17·20	17·35	16·08
Loss on ignition	—	11·95	—

The New Cransley Iron Co., Ltd., have their furnaces 1½ mile south-west of Kettering. They do not now work any ironstone independently themselves. Their predecessors, however, worked the ore at the surface in the neighbourhood of Cransley, chiefly, it seems, west of the furnaces, from 1877[3] onward for several years. But the full extent of these old workings has not been ascertained.

The Stanton Ironworks Company have their Orton pits, working the Northampton Ironstone, about a mile west of the Loddington Co.'s Orton pit and nearly two miles west of Loddington village. Their principal pit is on the south side of the Slade valley, but they have also two small abandoned workings immediately to the north on the farther side of the valley. In the principal pit work is proceeding in an east-north-easterly direction along a low ridge flanking the south side of the Slade valley. The working face at the east end shows[4] :—

	Ft. Ins.
Stony soil and remnants of boulder-clay, with *Lower Estuarine Series*— Local patches of pale blue sandy clay ...	3 ft. to 4 0
White bedded sand, variable	2 ft. to 4 0
Northampton Ironstone and Sand—	
Oolitic ironstone, all brown and much weathered, with much ' box-structure ' and cellular weathering ; average thickness	7 0
Sandy ' bastard ironstone ' (not worked)	3 ft. or 4 0

The average thickness of both cover and ironstone is 7 feet. Two small trough-faults running in a north-easterly or east-north-easterly direction, the more southerly passing a few yards north of Orton Lodge, and each having a downthrow of five or six feet at the working-face, let down the beds between them, so that water coming from the lower sandy beds in the floor of the pit and having no adequate outlet, causes some inconvenience.

All work is done by hand. No calcining is done at the pit, and the whole output is sent in the raw state to the Company's Stanton furnaces.

The following is an analysis[5] of the raw ore :—

Ore dried at 100° C.	Per cent.
Iron	38·5
Silica	23·8
Alumina	4·07
Lime	1·0
Magnesia	·43
Manganese oxide	·35
Sulphur trioxide	·32
Phosphorus pentoxide	1·58
Moisture (in ore as received)	21·68

[1] From the Ministry of Munitions.

[2] Average analysis from F. H. Hatch, ' Average Analyses of British Iron-ores and Ironstones produced in 1917–18 ' (*Ministry of Munitions of War*), 1918.

[3] ' Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

[4] The Old Series one-inch Geol. map represents this ground, and its continuation for about a mile in an east-north-easterly direction, as Lincolnshire Limestone capped by Upper Estuarine beds.

[5] From the Ministry of Munitions.

The Lamport Ironstone Company have four pits working the Northampton Ironstone in the neighbourhood of Lamport and Brixworth. Two of them, separated by the road to Northampton, are situated halfway between the two villages, and work the ironstone eastward and westward, with a considerable proved area of good stone extending northward to Lamport, and beyond it on the east side. The other two pits are situated one mile east-north-east, and half a mile east of Brixworth, the former near the south-eastern corner of a proved area extending half a mile westward and rather farther northward from it. The fourth pit has a prospective extension in proved ground for nearly a mile eastward; while workable ore extends south-westward from it to an old abandoned pit half a mile south of Brixworth. But between these three separate tracts known to contain workable ironstone at or close to the surface, much of the ground is heavily covered with boulder-clay, which a short distance east of Brixworth attains locally a thickness of 35 feet or more, and may in places be thick enough to prevent opencast working.

In the Lamport Company's workings cover and ironstone each average 7 feet in thickness. Work is done by hand-labour.

The following is a representative analysis[1] of the Lamport Company's ironstone:—

Raw ore as received.	Per cent.
Iron	33·82
Iron (dried at 100° C.)	40·40
Silica	15·30
Alumina	4·01
Lime	3·42
Magnesia	·17
Sulphur	·32
Phosphorus	·81
Moisture	15·27
Loss on ignition	12·97

The Brixworth Ironstone Company have workings on the north side of Brixworth, where they work two pits known as Wood South and Deep pits, the latter on the east side.

The average thickness of cover is 8 feet in the Wood South pit and 22 feet, with variation between 18 feet and 32 feet, in the Deep. The thickness of ore averages 10 feet and 9 feet respectively in the two pits, the upper part, about 6 feet in each pit, being regarded as good ironstone, and the lower part as poor stone. The cover, where thick, is removed by steam-navvy, but the ore is worked by hand. No calcining is done, the ironstone being sold in the raw state. Some of it goes to Derbyshire and some is used in the Northampton district.

The ore is regarded as variable, the chief difference being in its lime- and iron-contents. The more important constituents have been found by analysis to vary within the following limits in the raw ore as used by one company:—

	As received. per cent.	Dried at 100° C. per cent.
Iron	28·64—40·19	33·0—43·5
Silica	7·57—11·53	8·2—13·2
Lime	6·56—13·47	7·1—15·3
Moisture	7·60—13·20	—

But these figures apparently represent only the more calcareous varieties of the Brixworth ironstone.

The following are fuller analyses of different types of this ore:—

Raw ore as received.	I.[2] per cent.	II.[3] per cent.
Iron	31·02	27·96
Iron (dried at 100° C.)	35·00	—
Silica	18·90	8·92
Alumina	8·75	7·14
Lime	2·98	9·13
Magnesia	·59	—
Manganese	·28	·16
Sulphur	·07	trace
Phosphorus	·76	·55
Moisture	11·50	18·25

[1] From the Ministry of Munitions.
[2] From F. H. Hatch, *op. cit.* (averaged analysis).
[3] From the Ministry of Munitions.

These analyses show that the ore is divisible into calcareous and siliceous varieties. The more calcareous Brixworth ironstone contains an exceptionally high percentage of lime and in that respect is comparable with parts of the Kettering Company's ore. It is bought by one or more companies for the purpose of mixing with their own siliceous Northampton ore.

For several miles eastward from Lamport and Brixworth the ironstone is not worked.

At Burton Latimer the Burton Ironstone Company, owned jointly by the Staveley Coal and Iron Company and Messrs James Oakes & Co., have a series of workings extending from the railway due north of the village, southward by the east side of it, and beyond nearly to the Finedon Road. These pits are indicated on the map (Pl. VIII) by three separate areas of exhausted ground. The two larger worked areas lie on the north-west or upthrow side of a fault shown on the Geological map as trending in the direction of Cranford, and in these areas the ironstone is for the most part at or close to the surface. The third and least area of worked stone is situated south-east of Burton Latimer, on the downthrow side of the fault, and there the cover is on the whole thicker. The several workings are :—

Name of Pit.	Situation and Direction of Working.	Average Thicknesses. Cover. Ft.	Ins.	Ironstone. Ft.	Ins.
1. Cuckoo	Working respectively westward and eastward from the worked area near the railway north of Burton Latimer	6	0	3	0
2. Jackdaw		5	6	3	6
3. Burton	Working eastward, north-east of the village, on the east side of the large worked area	25	0	7	0
4. Osbourne's ...	A small abandoned working in the valley east of the fault and of the south end of the large worked area : worked northward ... ... up to	35	0	6	0
5. Finedon End ...	Working north-eastward at the south-east end of the most southerly worked area	15	0	5	0

In the Cuckoo pit the upper half of the thin cover consists mainly of sandy soil ; but the lower half consists of disintegrated brown oolitic ironstone weathering in place. The solid ironstone worked below is equally brown but less densely oolitic and decidedly sandy. In fact it is only the basal remnant of the ore. The lower half of the cover is riddled and gives the equivalent of 2 feet of first-class ironstone, better than the solid remnant below.

In the Jackdaw pit, in which the conditions are closely similar to those of the Cuckoo pit, the cover is divisible for working purposes into three parts :—

Cover :—

Upper part—Sandy soil.

Middle part—Mixture of sandy soil and weathered disintegrated brown oolitic ironstone (riddled).

Lower part—Disintegrated brown oolitic ironstone, almost undisturbed (scarcely needs riddling and is a very good ore).

Ironstone :—

Solid brown oolitic ironstone less sandy than in the Cuckoo pit, with numerous laminae of brown ferric oxide.

The lower and middle parts of the cover yield on riddling the equivalent of probably three feet of solid ironstone.

In the Burton pit the ironstone has passed eastward under a considerable thickness of cover, apparently before quite reaching the fault. It contains much green unoxidized ore at the north-east end of the 'face,' which there shows :—

	Ft.	Ins.
Soil with remnant of limestone	6	0
Upper Estuarine Series—		
Pale brownish-grey calcareous clay full of *Ostrea* ('pen-earth')	4	0
Dark grey calcareous clay full of *Ostrea* ('pen-earth')...	4	0
Pale brown and grey clay	1	0

	Ft.	In.
Lower Estuarine Series—		
White sand	4	0
Yellow sand	4	0
Northampton Ironstone—		
Brown and green oolitic ironstone	7	0

In Osbourne's pit an unusual increase of dip to 12 or 15 degrees in a north-easterly direction rapidly takes the ironstone down under thick cover, and this has apparently caused the pit to be abandoned when comparatively little work had been done. At the deep end the 'face' shows :—

	Ft.	Ins.
Remnant of limestone		
Oyster bed ('pen-earth')		
Black clay	35	0
Very silty clay		
Buff sand		
Northampton Ironstone—		
Brown and green oolitic ironstone	6	0

In the Finedon End pit the cover, consisting almost entirely of buff and white fine-grained sand-rock, varies in thickness up to 18 feet 6 inches, and the ironstone averages 5 feet between extremes of 3 feet and 9 feet. The surface of the ore undulates slightly, but there is said to be no proportionate thickness of ironstone below the level floor of the working under the troughs formed by the undulation ; *i.e.*, the workable ore varies in thickness with the undulations of its surface. The ironstone is rather hard, somewhat sandy (it is said to contain 20 per cent. of silica) and less oolitic than usual; it is well weathered on the whole, with a good deal of small 'box-structure,' and comparatively little green ore except near the bottom ; but exceptionally the top bed is green-hearted.

At the south-east end of the working a fault running in a south-south-easterly direction throws down the oyster-bed of the Upper Estuarine Series on the east side to the level of the ironstone on the west side and thus puts an end to open-cast working.

All work is done by hand-labour. The green stone and very wet brown stone are calcined. Nearly all the output is taken by the Staveley Co. and Messrs. Oakes for their own furnaces, but a little is sold and goes to Wellingborough.

The following are analyses[1] of the Burton Company's raw ironstone :—

Ore as received.	I.	II.	III.
Iron	37·61	30·93	32·72
Iron (dried at 100° C.) ...	[42·59]	[37·49]	38·10
Silica	15·89	22·69	20·85
Alumina	5·12	2·96	6·03
Lime	2·29	·70	1·17
Magnesia	·22	·44	·13
Oxide of manganese	·41	—	·13
Sulphur	·097	·10	·075
Phosphorus	·58	·47	·52
Water	11·70	17·51	16·11
Loss on ignition	11·12	—	10·35

A short distance east of the Burton Company's workings two trial-holes were sunk, on the north side of the stream-valley, in positions (*a*) half a mile E. 18° S., and (*b*) five-eighths of a mile E. 6 N. from Burton Latimer Church. Of these trials (*a*) proved 8 feet of workable ironstone close to the surface, and (*b*) 13 feet 8 inches of ironstone, of which 9 feet was of workable quality, under 33 feet of cover. The workable ore of these two trials contained respectively 47·85 per cent. and 45·19 per cent. of iron in the calcined state.

Nearly two miles east of Isham Station, or three-eighths of a mile due east of trial (*a*) a well was sunk in 1901, near Burton Wold, to a depth of 299 feet 4 inches.[2]

[1] From the Ministry of Munitions.

[2] For the complete record of this well, *see* "Water Supply of Bedfordshire and Northamptonshire" (*Mem. Geol. Surv.*), 1915, p. 81. *See* also Pl. VII, Section 1.

In this a bed of 'dark grey very compact heavy sandstone,' 8 feet thick, the top of it at a depth of 63 feet, is generally accepted as being the Northampton Ironstone by the ironstone companies interested in the district.

Mr. Charles Barlow has worked a considerable area of the ironstone on the north-west and west sides of Finedon, as shown on the map (Pl.. VIII), where the exhausted area includes several pits already worked out and closed. The present working pits are, in order southward :—

Name of Pit.	Situation and direction of working.	Thickness of beds. Cover. Ft.	Ins.	Ironstone. Ft.	Ins.
1. Jacques	Working north-eastward, at extreme N.E. corner of exhausted area (this pit, opened by Mr. Barlow, is no longer controlled by him, but is still working)	22	0	—	
2. Finedon Glebe ...	Working north-eastward, on north-east side of road to Finedon Station, and extending from a quarter to half a mile north-west of Finedon (now leased to the Wellingborough Iron Co., but worked for them by Mr. Barlow)	10	0	10	6
3. Leonard's Grass ...	Working south-westward, on the south-west side of road to Finedon Station, opposite to northern half of Finedon Glebe pit: work now nearly finished ... up to 15 or	16	0	9	0
4. Cricket Field ...	Working north-eastward, on the north-east side of the same road and adjoining the south end of Finedon Glebe	10	0	9	0

The following general sections were noted :—

Finedon Glebe Pit.

	Thickness. Ft.	Ins.
Lower Estuarine Series :—		
Sands and clays, which at the north-west end thin out and disappear at the surface, but at the north-east end have a thickness of	10	0
Northampton Ironstone :—		
At the north-west end, weathered and disintegrated brown oolitic ironstone (4 ft.), forming 'cover' above solid ironstone below, but passing south-eastward under sands and clays, and there becoming brown, moderately hard and somewhat calcareous oolitic ironstone, with much 'box-structure,' about	3	6
Similar ironstone, but rather sandy and less densely oolitic, with a few green cores at south-east end (near the top of it a thin band of blue dense and non-oolitic carbonate ironstone), about	4	6
Rather inferior and more sandy ironstone	2	0

The 4 feet of disintegrated ironstone that makes the only cover above the solid lower stone at the north-west end of the working, yields on riddling very good ore, better than the solid stone below.

Leonard's Grass Pit.

The cover consists of Lower Estuarine sand and clay in the southern part of the pit, but in the northern part of a much less thickness of ironstone rubble mixed with sand and clay. The ironstone in the present working-face at the south end is harder and more massive than elsewhere, except the lower part of it.

Much of the ground in this pit was worked over about 35 years ago, when apparently only the upper part of the stone was extracted. It is said that a great deal of really good stone was then thrown over and wasted, which would almost repay working again.

Cricket Field Pit.

	Thickness. Ft.	In.
Upper and Lower Estuarine Series—		
Oyster-bed ('pen-earth'), up to	5	0
Yellow and brown ferruginous sand (a conspicuous band) uneven, and discordant from the beds below	0	3
Pale blue very fine-grained silty sand, up to	5	0
Brown iron-stained and iron-cemented sand amounting almost to a siliceous ironstone ('bad sandy stone': rejected), about	1	6
Northampton Ironstone—		
Brown oolitic ironstone, rather massive	3	0
Similar ironstone, with some shell-beds, in which the shells are dissolved, and blue cores of good unweathered stone in lower part, about	7	0

The following are analyses of Mr. Barlow's Finedon ironstone:—

—	Raw ore, as received. I.[1]	Raw ore, dried at 100° C. II.[2]	Calcined ore. III.[2]
	Per cent.	Per cent.	Per cent.
Iron (as received)	33·97	—	41·76
Iron (dried at 100° C.) ...	38·87	36·20	43·50
Silica	14·20	18·28	20·80
Alumina	7·25	9·93	7·11
Lime	2·69	2·71	3·00
Magnesia	·75	—	—
Manganese	·40	—	—
Sulphur	·16	—	—
Phosphorus	·53	—	1·63 (P_2O_5)
Moisture	12·61	11·40	4·40
Loss on calcination	—	—	4·60

All the above pits are worked opencast by hand-labour. Much of the output is calcined, chiefly green and wet stone, but also all ore worked above requirements for despatch at the time. There is no treatment of the ore at the pit: the lowest and most sandy beds are left unworked.

The Ebbw Vale Steel and Coal Co., Ltd., have as part of their property in the Irthlingborough district a disused working at the east end of Finedon Park, less than half a mile west of the cross roads at Finedon. The ore has an average thickness of 6 feet under 2 feet of cover. In a trial about 200 yards north-west of the cross roads the ironstone, 7 ft. 6 ins. thick, was found on analysis to contain 49·88 per cent. of iron in the calcined stone.[3]

A partial analysis[4] of the Ebbw Vale Company's Finedon Park ironstone (raw ore, as received) gives:—iron 30 per cent., siliceous matter 8 per cent., and moisture 13 per cent.

The Wellingborough Iron Company's leases extend from the south-east side of Finedon, south-eastward to the road at Ditchford, half a mile west of Irthlingborough.

[1] From F. H. Hatch, *op. cit.* (averaged analysis).
[2] From the Ministry of Munitions.
[3] From the Ebbw Vale Steel and Coal Co.
[4] From the Ministry of Munitions.

Their present workings are :—

Name of Pit.	Situation and direction of working.	Average thickness of beds. Cover.	Ironstone.
		Ft.	Ft.
1. Finedon No. 1 ...	Working south-eastward, on the south-east side of Finedon ...	37	7–12
2. Thingdon Quarry..	One mile due south of Finedon..	6	8
2. Neilson Mine ...	One mile due south of Finedon : working eastward	—	—
3. Carrol Spring Pits, 5 and 5A.	1½ miles due south of Finedon, on the east side of the Stanton Co.'s ground, and on south or up-throw side of fault : working eastward	25[1]	7½
4. Ditchford No. 9 ...	½–1 mile W.S.W. of Irthlingborough : No. 9 working northward, and No. 10 northwestward from the western and north-eastern members of the exhausted area there indicated on the map.	19	8
4. ,, No. 10 ..		20	10

Nearly all the stone is obtained still by opencast, the only exception being the Neilson Mine. But in the near future the greater part of the leased area will no doubt require mining.

The following sections in the several pits show the character of the beds :—

Finedon No. 1 Quarry.	Thickness. Ft.	Ins.
Great Oolite Limestone—		
Limestone, about	16	0
Upper and Lower Estuarine Series—		
Grey clay	3	6
Black clay, about	1	0
Pale green silty sand with green clay streaks	9	0
Alternate hard bands of pale sandy limestone and calcareous sandstone, base obscured, perhaps	6	0
Northampton Ironstone and Sand—		
Upper half (best stone) ; well-weathered brown oolitic ironstone, with much deposit of brown oxide in joints and bedding-planes ('box-structure) : lower half, less weathered brown and green-hearted oolitic ironstone ; the whole varying in thickness from 7 ft. to 12 ft. ; average about	10	0
Very fine-grained grey silty and muddy sand-rock, suggesting a gradual passage down to Upper Lias clay. (There is said to be 'hard rock' below)...	—	

In some parts of this pit, if not throughout it, there is said to be, immediately above the main ore-bed, 'hard blocks of carbonate,' often thickly veined with red. Specimens show a dense carbonate ironstone for the most part structureless, but in some cases sparsely oolitic. They appear to represent a bed of nodules or bullions with a maximum thickness of 2 feet.

The greatest thickness of cover in this pit is 42 feet.

Carrol Spring No. 5a Quarry.	Ft.	Ins.
Cover	9	6
Northampton Ironstone :—		
Brown and green sandy oolitic ironstone containing green ooliths in varying amount in a brownish-black sandy matrix (the whole of this is regarded as too siliceous for use and is rejected as 'bad sandy stone' ; but it seems to belong essentially to the ironstone, though counted as 'cover') : thickness about...	9	0
Massive brown and green oolitic ironstone, varying in thickness from 3 or 4 ft. to 10 ft. : average about ...	7	6

[1] Including about 9 feet of inferior sandy ironstone which seems to belong strictly to the ironstone-bed.

The thickness of cover is somewhat greater in other parts of the pit.

Ditchford No. 9 Pit.

	Thickness. Ft.	Ins.
Glacial—		
Boulder-clay, about	3	0
Lower Estuarine Series—		
Pale blue sandy clay, about	16	0
Northampton Ironstone and Sand—		
Brown oolitic rather massive ironstone, with large green-hearted blocks in lower part, and irregular 'box-structure' on large scale : average thickness about ...	8	0
Brown thin-bedded sandy ironstone (not worked), varying from	1 ft. to about 2	6
Blue sandy stone, about	4 ft. to 2	0
Upper Lias—		
Blue clay	—	

Ditchford No. 10 Pit.

The cover is similar to that of No. 9, but with a greater proportion of boulder-clay and an average total thickness of 20 feet or rather more. The ironstone averages about 10 feet. It looks rather stronger and more massive than that of No. 9, but otherwise similar. About 2 feet above the base of the worked stone is a thin bed of blue dense and structureless carbonate-ironstone like that of Islip and Finedon (see pp. 184, 194.)

The cover is removed by steam-navvy, the ironstone worked by hand, with some blasting.

About half the ore, including all the green stone, is calcined, some in clamps and some in kilns. The ore is smelted at the Company's Wellingborough furnaces on the north-east side of the town. Only Northampton Ironstone is used. Foundry- and forge-irons are made, but no basic iron.

The following are partial analyses[1] of the raw ore from some of the Wellingborough Company's pits :—

Name of Pit. *Ore dried at 100° C.*	Finedon No. 1. Per cent.	Thingdon. Per cent.	Carrol Spring. Per cent.	Ditchford No. 9. Per cent.
Iron	37·9	36·0	40·7	38·7
Silica	10·5	12·0	13·1	12·0
Alumina	7·3	—	8·3	8·8
Lime and Magnesia ...	3·4	Lime 2·5	2·2	2·7
Loss on calcination ...	21·2	—	14·4	17·2

	Non-oolitic carbonate-ore immediately above main ironstone (*see* p. 196). Per cent.
Iron	35·4
Silica	13·2
Alumina	4·5
Lime	2·6
Magnesia	1·84
Phosphorus pentoxide	·52
Loss on ignition of dry ore	25·70

In the Stanton Ironworks Company's Wellingborough pits immediately west of the Wellingborough Company's Carrol Spring workings, all the ore is now mined underground, on the north or downthrow side of a fault (*see* above, p. 196), but at very shallow depth, beginning at 25 feet and increasing to 40 feet. The direction of mining is north-eastward in the small area remaining north-east of the lane joining the Thrapston and Irthlingborough roads, in the north-east corner of the lease. The greater part of the ground has now been worked out, most of it by opencast in former years.

[1] From the Ministry of Munitions.

The thickness of the mined stone varies from 6 feet to 10 feet with an average of 8 feet 6 inches. Mining is done on the pillar-and-stall principle, and it is estimated that one third of the ore is left in as pillars. A thickness of about 7 feet is got out first, the remainder, up to 3 feet, being left in as roof, but this is brought down on working back. The stone is blasted. All the output goes to the Stanton Company's furnaces, in the raw state.

An analysis of the Stanton Company's Wellingborough ironstone is as follows[1]:—

Ore dried at 100° C.	Per cent.
Iron	38·5
Silica	14·8
Alumina	7·5
Lime	3·0
Magnesia	1·08
Manganese oxide	0·43
Sulphur trioxide	0·37
Phosphorus pentoxide	2·03
Moisture (in ore 'as received')...	19·1

The Southhill Ironstone Mines, Ltd., work the Northampton Ironstone at the surface in the ground immediately south of the Stanton Company's lease, 1 mile east-north-east of Wellingborough. The ironstone is a well-weathered brown ore, worked opencast by hand under little or no cover. The output is sold in the raw state. The following is an analysis[2] of the ore:—

Ore, as received.	Per cent.
Iron	31·98
Iron (dried at 100° C.)	38·28
Silica	15·52
Alumina	—
Lime	0·97
Magnesia	0·03
Manganese	0·17
Sulphur	0·03
Phosphorus	0·60
Moisture	16·40

Mr. W. Partridge works the ironstone at the Cement Works at the south-west end of Irthlingborough village, the Cement Company working the underlying Upper Lias clay.

The average thickness of the ironstone as got is 6 feet, under the same thickness of cover. The ore, a brown weathered stone, is worked opencast by hand, in a small pit with a working-face 150 feet in length. The output is sold in the raw state. The following is a partial analysis[3]:—

	Per cent.
Iron (dried at 100° C.)	38·0
Silica ,, ,, ...	17·0
Lime ,, ,, ...	2·5

The Ebbw Vale Steel and Coal Company, Ltd., hold an extensive area of Northampton Ironstone, extending from a point eastward of Burton Latimer, southward to the southern outcrop of the ironstone on the west side of Irthlingborough, at or beyond the road from that village to Wellingborough.

Early in the summer of 1918 preparations had been made to mine the stone on a large scale from an adit starting below the road and running north-west. Two shafts were sunk on the tunnel from the adit, one known as the Trial Shaft (Lat. 52° 19′ 5″ N.: Long. 0° 37′ 25″ W.), near the middle of the tunnel, rather more than a quarter of a mile from the road, and the other, known as No. 2 (Lat. 52° 19′ 15″ N.: Long. 0° 37′ 50″ W.), at the end of the tunnel a little more than half a mile from the road.

The Trial Shaft is immediately north of a fault proved in the tunnel with downthrow south, there amounting to about 20 yards. This fault lies about a

[1] From the Ministry of Munitions.
[2] From F. H. Hatch, *op. cit.*: averaged analysis.
[3] From the Ministry of Munitions.

quarter of a mile north of that shown on the one-inch Geological Map as running in approximately the same direction, but with downthrow north. It is not unlikely there may be here a belt of parallel trough-faulting (*see* Pl. VII, Section I).

Sections of the strata proved in these two shafts[1] are given below :—

	Thickness. Ft. Ins.	Depth. Ft. Ins.
No. 2 Shaft.		
Glacial—		
Boulder-clay	26 6	—
Great Oolite Limestone—		
Limestone	23 6	50 0
Estuarine Series—		
Clay	6 9	—
Limestone [*Estuarine*]	5 6	—
Clay	0 6	—
Estuarine clays, etc.	9 3	—
Northampton Ironstone—		
Ironstone (oxidized)	9 0	—
Ironstone (carbonate)	3 0	84 0
Upper Lias—		
Blue clay	—	—
Trial Shaft.		
Loam...	1 4	—
Glacial—		
Boulder-clay	3 0	—
Great Oolite Limestone—		
Blue and pink-tinted limestone, very shelly ...	3 0	—
Limestone, very shelly	0 10½	—
Coarse-grained calcareous rock	0 9½	—
Blue fossiliferous limestone (with reddish-brown marl 2 ins. and clay and shells 3½ ins.) ...	0 9½	—
Fossiliferous limestone	0 6	—
Fossiliferous marl	1 3	—
Blue limestone	2 10	—
Blue and yellow fossiliferous marl	1 0	—
Grey limestone	0 8	—
Estuarine Series—		
Grey fossiliferous clay	2 0	—
Hard green stone	0 6	—
Neutral grey clay	1 0	—
Green clay	1 6	—
Neutral grey clay	1 2	—
Green clay	1 1	—
Green clay, very hard	1 5	—
Green clay, hard	1 10	—
Neutral grey clay	0 5	—
Limestone	0 7	—
Limestone, fossiliferous	0 9	—
Neutral-tinted arenaceous clay	0 10½	—
Limestone	0 7	—
Limestone, fossiliferous	2 0	—
Northampton Ironstone—		
Ironstone, argillaceous	7 11	—
Ironstone, hard bed	2 3	—
Ironstone, arenaceous	2 0	—
Ironstone, red and green	1 0	—
Ironstone, green carbonate...	3 5	—

[1] From the Ebbw Vale Steel and Coal Co., Ltd.

The section proved in a well, known as the New Well (Lat. 52° 19′ 4″ N.: Long. 0° 37′ 1″ W.), at the west end of Irthlingborough village, north of the Wellingborough road and one quarter of a mile almost due north of the Ebbw Vale Co.'s adit, is as follows[1] :—

	Thickness. Ft.	Ins.
Soil	1	0
Cornbrash—		
Limestone...	2	0
Great Oolite Clay—		
Clay	11	6
Great Oolite Limestone—		
Limestone...	0	6
Clay	1	6
Limestone...	23	6
Upper [*and* (*?*) *Lower*] *Estuarine Series*—		
Clay and marl	3	0
Blue clay	2	0
Yellow clay	1	6
Blue rock (*Estuarine* limestone), coated with iron	5	6
Blue clay	2	0
Red rubble and clay	3	0
Northampton Sand [*with Ironstone*]—		
Ironstone and white sand mixed	1	6
Ironstone (depth 61 ft.)	2	6
Dark blue rock with iron	5	0
Red sandstone	4	0
Blue rock coated with iron	12	6
Clay	1	6
Blue rock	3	0
Upper Lias—		
Clay (depth 97 ft.)	10	0

The well may have been sunk upon a small fault, one of those already mentioned, for there is little or nothing to represent the Lower Estuarine beds, which however, are variable.

It is expected that the average thickness of workable ironstone in the Company's mines will be fully 8 feet, and that it may actually be nearly 10 feet. At least one foot of ore will have to be left for a roof; but as much as possible of this will be recovered in the final working: and it is hoped to get at least 85 per cent.—and probably more—of the assumed thickness of 8 feet.

The ore is largely, but not entirely, in the green unweathered carbonate state. Between Finedon and Foster's Lodge, one and a half miles farther east, the ironstone bed is considered to be particularly good and to contain some of the best ore in the whole district, while it is believed that the trialing done proves practically all the ground to contain workable ironstone, from the Islip furnaces on the east and the Burton Company's leases on the west, southward to the outcrop in the valley west of Irthlingborough.

The following is an average analysis[2] of the ironstone at No. 2 Shaft, 10 feet of ore being represented in the analysis, exclusive of the lowermost 3½ feet:—

		Per cent.
Calcined ore ...	Iron	46·34
	Silica	13·12
	Lime	6·20
	Magnesia...	2·62
	Manganese	0·17
	Phosphorus	0·751
Raw ore dried at 100° C.	Sulphur	0·53
	Loss on calcination ...	24·55
Raw ore, moist ...	Loss on calcination ...	31·72

[1] Reproduced from 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*), 1909, p. 112.

[2] From the Ministry of Munitions.

An analysis made of another sample was[1] :—

—	Upper 8 feet.			Lower 4 feet.		
	Raw Ore.		Calcined Ore.	Raw Ore.		Calcined Ore.
	Moist.	Dried.		Moist.	Dried.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	32·78	36·30	49·86	28·84	30·29	39·65
Silica	7·40	8·20	11·26	18·37	19·30	25·25
Lime	4·15	4·60	6·32	3·23	3·40	4·45
Sulphur... ...	0·33	0·37	—	0·47	0·50	—
Phosphorus ...	0·42	0·46	0·63	0·30	0·32	0·42
Moisture ...	9·68	—	—	4·80	—	—
Loss on calcination	34·24	27·26	—	27·26	23·60	—

The ironstone, which it is expected will be worked at the rate of 2,000 tons a day, will be mined on the pillar-and-stall principle. The output will supply the Company's Ebbw Vale furnaces in South Wales, and will be used for the production of basic steel. The ore will be calcined in kilns at Irthlingborough.

It is said that at distances of a mile west and south-west of Little Addington thicknesses of ironstone ranging from 19 feet to 29 feet have been proved underground, but the accuracy of the statement cannot be guaranteed.

In the neighbourhood of Raunds, east of the Nene Valley, a well at the old limestone quarry, less than half a mile west of the village, proved 14 feet of ironstone, the lower part hard and blue, at a depth of 20 feet, where, according to the well-section, it lies immediately below the Great Oolite Limestone. Another well south-west of the village proved the ironstone to be only 7 feet 2 inches, with a pyritous bed in the lower part; and a third well at the brickworks east of Raunds showed a farther reduction to 5 feet of hard and very pyritous ironstone.[2]

A well[3] three-quarters of a mile north-east of Higham Ferrers, at 'Red Links' near the Chelveston Brook proved 8 feet 3 inches of 'fairly rich, cellular ironstone' at a depth of 12 feet 5 inches.

Another trial well on the Bedford road south of Rushden gave the thickness of ironstone as only 3 feet at a depth of 102 feet.[4]

Messrs. Butlin, Ltd., have worked out in former years a certain amount of ironstone in the proximity of their Irthlingborough furnaces, situated one mile east of Wellingborough, on the east side of the railway; but they were not working ironstone themselves in 1917.

The Midland Brick Co. are getting the ironstone on the east side of Wellingborough, west of the railway and immediately south of the Wellingborough Iron Co.'s furnaces. The pit has a working-face about 900 feet in length, and the direction of working is west from the outer edge on the eastward slope of the ground. As, however, the ironstone crops out near the top of the rise, the amount of cover averages only 5 feet to 10 feet, and in some parts is less. The following is a typical section of the beds, near the south-west end of the pit :—

	Ft.	Ins.
Soil, remnants of boulder-clay and disintegrated ironstone about...	2	0
Brown weathered oolitic ironstone, broken and mixed with soil, about	5	0
Solid ironstone, oolitic, brown and well-weathered ...	4	0
Sandy ironstone (not worked), about	1	0
Loamy sand, about	1	6
Blue clay (Upper Lias)	—	

[1] From the Ebbw Vale Steel and Coal Co., Ltd.

[2] For complete sections of these wells, *see* 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*), 1909, pp. 147–8.

[3] *Op. cit.*, p. 108, where the position of the well is given wrongly as N.W. of Higham Ferrers.

[4] *Op. cit.*, p. 151.

Boulder-clay in some cases descends in pockets ('gulls') into the ironstone. The broken upper bed of the stone is riddled to free it from sand and soil. The general thickness of the ore, including this broken bed, is 9 feet or 10 feet. The average iron- and silica-contents in the raw ore as received are given as—iron 34 per cent., silica 19 per cent.[1]

All work is done by hand. The output is sold. Most of it is used in the neighbourhood, but a small proportion is sent to Middlesbrough.

The full extent of the old ironstone-workings at and near Wellingborough, including those at Red Well half a mile north-west of the town, has not been ascertained.

Southern Part of Main Northampton Ore-field.

Messrs. James Pain, Ltd., hold leases of Northampton Ironstone west and south of Irchester, but have so far worked only a small part of this ground at their Wellingborough pit, west of Irchester, from which the general direction of working is south-eastward. In this pit, with a working-face 1,800 feet in length, the average thickness of cover is 12 feet, of ironstone 9 feet. The cover is removed by steam-navvy, the ironstone worked by hand. The output is sold in the raw state.

Analyses[2] of the raw ironstone are appended:—

—	I.	II.	III.	IV.
Ore, as received.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	32·0	33·33	34·47	34·81
Iron (dried at 100° C)	—	37·80	39·00	—
Silica	10·9	14·11	13·90	12·02
Alumina	—	7·63	8·53	—
Lime	2·13	2·38	4·30	1·08
Magnesia	—	0·60	—	—
Manganese	—	0·167	—	—
Sulphur	—	0·043	—	—
Phosphorus	0·84	0·608	1·14	—
Moisture	—	11·8	11·60	11·13
Loss on ignition	—	—	13·60	—

A well in Irchester proved the ironstone, at a depth of 11 feet, to have a thickness of 9 feet 6 inches, the upper part being red and broken, the lower part a hard ironstone-rock.[3]

Another well at the Wilby Waterworks, half a mile north of the village of Wilby, and one and a quarter miles south-west of Wellingborough showed 11 feet of ironstone-beds at a depth of 33 feet 9 inches.

The Earls Barton Ironstone Company work the Northampton Ironstone at Earls Barton, and have proved and leased an extensive tract of surface-ore, capping the plateaux for at least 2½ miles north-westward and 1½ miles north-eastward from Earls Barton. They have two pits working at Earls Barton, the principal one (Doddington pit) half a mile east and a smaller (New Barton pit) a little farther north, at the north-east end of the village.

In the Doddington pit, working north-eastward on the north side of the road to Great Doddington, the cover varies from 4 feet to 18 feet and the ore averages 6 feet, between limits of 4 or 5 feet and 8 feet. A section in the middle of the working-face, which has a length of 1,200 feet, showed:—

	Ft.	Ins.
Soil	2 ft. to 3	0
Lower Estuarine Series—		
Blue clay, uneven, up to about	1	0
White sand, about	13	0
Northampton Ironstone—		
Brown oolitic ironstone, rather massive, with 'box-structure,' about 1 foot at the top looking rather sandy: very little green stone in lower part, about	8	0

[1] From the Ministry of Munitions. [2] *Id.*

[3] 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*), 1909, p. 110.

In the New Barton pit, with a working-face 150 feet long, the cover consists of merely 4 feet or 5 feet of soil with disintegrated ironstone, and the solid ore below, brown and well weathered, has a similar thickness.

The following analyses illustrate the character of the Earls Barton ore :—

—	Moist Ore.	Ore dried at 100° C.			
	I.[1] (averaged)	II.[2] Dodding-ton pit, road end.	III.[2] Dodding-ton pit, middle.	IV.[2] Dodding-ton pit, bottom end.	V.[2] New Bar-ton pit.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	28·69	—	—	—	—
Iron (dried at 100° C.)	34·00	37·24	39·60	41·55	42·60
Silica	17·05	23·40	17·60 (Insoluble	16·80 Alumina.	15·80
Alumina	10·21	4·34	4·58	4·87	4·72
Lime	·42	2·00	4·00	3·00	1·10
Magnesia	·39	—	—	—	—
Manganese	·27	·56 (MnO)	·56 (MnO)	·37 (MnO)	·46 MnO
Sulphur	·17	—	—	—	—
Phosphorus	·60	1·66 (P_2O_5)	1·75 (P_2O_5)	1·57 (P_2O_5)	2·02 P_2O_5)
Moisture	15·60	20·86	18·00	18·50	26·10
Loss on ignition ...	—	14·80	14·40	14·00	14·60

The working (opencast) is at present done entirely by hand. The whole output goes in the raw state to the furnaces of the Shelton Iron, Steel and Coal Co., Ltd., the Midland Coal, Coke and Iron Co., Ltd. (North Staffordshire), and the Stanton Ironworks Co., Ltd. (Derbyshire), joint owners of the Earls Barton Ironstone Co.

South-western District : Northamptonshire.

The Whiston Ironstone Co., Ltd., work the same ironstone south-west of Whiston, on the south side of the Nene Valley.

The outcrop of the stone at the Company's workings is narrow, and the ground rises westward into a spur of relatively high ground capped by the Great Oolite Limestone. The ironstone is being worked westward through the north end of this spur. Consequently the cover, comparatively thin at the north end of the working-face, which has a length of nearly 1,800 feet, increases to a considerable thickness towards the south end, and ranges from 5 feet to about 30 feet. The ironstone increases from barely 5 feet at the outcrop to 8 feet, below which is 2 feet or 3 feet of sandy very siliceous stone, not worked.

The ironstone lies nearly flat in the northern and southern parts of the pit : but locally, near the middle, it assumes a decided eastward dip and rises obliquely into the working-face. A section of the beds near the north end (Firs Spinney) showed :—

	Ft.	Ins.
Upper and Lower Estuarine Series—		
Pocketty soil and remnants of disturbed blue flaggy crystalline limestone (' Estuarine Limestone ') from 3 ft. to	1	6
Brownish-blue clay resting on strongly undulating surface of sand below, with suggestion of differential movement, or erosion, from	1 ft. 6 ins. to 3	0

[1] From F. H. Hatch, *op. cit.*

[2] From the Earls Barton Ironstone Co.

	Ft.	Ins.
Fine-grained white quartz-sand, with strongly undulating or pockety upper surface, and becoming a hard yellow sand-rock at the bottom: variable, about	5	0
Pale blue fine-grained silty sand, about	1	6
Northampton Ironstone—		
Brown, densely oolitic ironstone, rather soft, close-jointed, with many laminæ of brown ferric oxide along joints and bedding-planes, so as to produce an irregular 'box-structure': no green cores: about	6	6
Hard sandy ironstone, scarcely seen: said to be ... 2 ft. to	3	0

The surface of the ironstone bed hereabouts is slightly stepped with little faults in a direction about N.E.—S.W., with individual displacements of less than 1 foot mostly down north-west. The effect of these seems to be neutralized by a tilting of the beds between the faults.

In the southern half of the working the 'Estuarine Limestone' above the sand and clay is seen to have a thickness of apparently about 5 feet, and is succeeded by more silty sands and clays. The ironstone contains few green cores in any part of the working-face. Some of it is fossiliferous, with abundant shell-casts.

Analyses of the raw Whiston ironstone are as follows:—

	I.[1]	II.[2]	III.[2]	IV[2].
Ore, as received.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	37·812	38·37	34·009	33·22
Iron (dried at 100° C.)	39·775	—	—	—
Silica	18·138	15·91	14·054	14·120
Alumina	4·617	6·37	5·783	7·335
Lime	3·089	2·53	3·169	2·478
Magnesia	·548	·40	Nil.	·314
Manganese	·171	·15	·192	·207
Sulphur	·050	·056	·035	·029
Phosphorus	·586	·702	·684	·864
Moisture...	4·935	6·40	12·323	14·362
Loss on ignition ...	12·263	11·81	—	—

The ironstone is worked opencast. Thick cover is removed by steam-digger, all other work being done by hand. No blasting is done, as the ore is close-jointed and loose. The output is sold in the raw state. The limestone of the cover is sold for fluxing.

A well at Great Houghton,[3] on the south side of the railway, two miles east-south-east of Northampton proved green ironstone 12 feet thick at a depth of 65 feet.

The old workings of the Staveley Coal and Iron Company at Duston (about a mile west of Northampton), where ironstone was worked first in 1859,[4] were closed in 1909. The thickness of ironstone there worked is said to have been as much as 25 feet, but nothing like the full thickness can now be seen in the old working-face, which shows about 15 feet of the brown-weathering ferruginous sandstone ('Variable Beds': *see* pp. 141–2) developed locally just above the iron-ore. The sandstone contains marine fossils and brown laminæ of ferric oxide.

The Hunsbury Hill Ironworks (Executors of the late P. Phipps) are situated a little more than a mile west-south-west of Northampton.

[1] From the Whiston Ironstone Co., Ltd.

[2] From the Ministry of Munitions.

[3] 'Water Supply of Bedfordshire and Northamptonshire' (*Mem. Geol. Surv.*). 1909, p. 102.

[4] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

The Company's ironstone pits are :—

(*a*) Danes Camp : Two-thirds of a mile south-east of the furnaces.

(*b*) Wootton : Extending from 1 mile to 2¼ miles south-east of the furnaces, as far as the village of Wootton.

(*c*) Blisworth : on the east side of the town : old workings also on the west side.

A considerable area has also been worked out at Hunsbury Hill close to the ironworks.

The thickness of cover ranges from nil to 17 feet or 18 feet at Danes Camp, and the maximum thickness at Wootton is the same. The ironstone averages 8 feet – 9 feet at Danes' Camp and 9 feet – 10 feet at Wootton. The sandstone of the 'Variable Beds' above the ironstone has a thickness of 9 feet – 11 feet in these two pits.

The working-face in the middle of each of these pits showed :—

	Danes' Camp.	Wootton.
	Ft.	Ft.
Glacial—		
Boulder-clay (local) with flints and Bunter quartzite-pebbles...	3 to 4	—
Lower Estuarine Series—		
Sand	—	Nil to 4
'*Variable Beds*'—		
Bedded ferriferous sandstone, buff, brown or green	10 to 11	About 9
Northampton Ironstone—		
Brown oolitic ironstone, with 'box-structure' and cellular weathering in the later stages : beds of densely oolitic green-hearted stone in the lower part at Wootton : very little green stone at Danes' Camp : thickness up to ...	9 or 10	About 10
Upper Lias—		
Blue clay	—	—

Undulation of the strata brings up the Upper Lias clay to the surface in the south-west part of the Danes' Camp pit. There are no sandy beds at the base of the ironstone.

In the Wootton pit the sandstone above the ironstone changes in a few yards from a hard green or brown stone superficially resembling the ironstone below, to a soft buff sandstone or sand similar to the sands of the Estuarine beds. However, the failure of the 'box-structure' and cellular weathering of the ironstone to pass up into the sandstone serves readily to distinguish the two beds.

The following are analyses[1] of the ironstone of the separate workings :—

—	Danes' Camp.	Wootton.				Blisworth.
	I.	II.		III.		IV.
Raw ore (monthly averages)	Moist.	Moist.	Dried.	Moist.	Dried.	Moist.
	%	%	%	%	%	%
Iron	28·33	37·31	44·9	31·39	38·7	38·84
Siliceous matter ...	14·71	10·31	12·4	12·65	15·6	10·98
Lime	—	1·75	2·1	1·46	1·8	—
Magnesia	—	0·44	0·52	0·28	0·35	—
Manganese... ...	—	0·12	0·14	0·12	0·14	—
Phosphorus ...	—	—	—	0·6	0·74	—
Moisture	26·8	16·9	—	18·9	—	20·4
Loss on calcination	—	—	—	—	—	10·92

[1] From the Hunsbury Hill Ironworks.

Cover and ironstone are both worked by hand (opencast); where thick, the cover is removed in two lifts. The ore of the three pits is mixed together with Brixworth ironstone, for the production of forge- and foundry-iron. In 1918 basic iron was being made, after addition of manganese-ore.

Mr. R. B. Sparrow has pits working the Northampton Ironstone in the neighbourhood of Gayton. The ore has been worked out from the south side of that village eastward beyond the railway as far as the old Blisworth workings on the west side of Blisworth (*see* above). But a considerable area of proved ground remains for working on the east and north-east sides of Gayton, and also north of the ground exhausted on the east side of the railway. The latter tract is now being worked westward from its junction with the old Blisworth workings. Much of this tract has been worked over once in former years, so that only the lower part of the ironstone remains.

The cover in the present workings is consequently thin, ranging from 4 feet to 7 feet, and consisting largely of earth mixed with broken ironstone, some of which is saved by riddling. The thickness of ironstone now worked averages 5 feet – 6 feet. It is a brown oolitic ore thoroughly weathered and thin-bedded, and on analysis shows the following composition:—

Average Analysis for 1917.[1]

	As received. Per cent.	Dried at 100° C. Per cent.
Iron	37·178	43·637
Silica	9·47	11·12
Alumina	6·15	7·23
Lime	1·55	1·83
Magnesia	Trace.	Trace.
Manganese	0·232	0·273
Sulphur	0·044	0·052
Phosphorus	0·735	0·863
Moisture	14·80	—
Combined water and alkalies ...	12·96	15·22

The ground on the south-west side of the exhausted area south of Gayton (Gayton Wilds) has been proved by trialing to contain green ore, not suitable for present requirements, under an increased thickness of cover.

The ironstone is worked opencast entirely by hand. Surplus ore not required for sending off at once is sometimes calcined at the pits. The whole output is sold and goes to Yorkshire, North and South Staffordshire and Shropshire.

The Towcester Mineral and Brick Company have ironstone-workings about a mile and a half north-east of Towcester; and have worked out two tracts there, separated by the road to Blisworth, and a third smaller tract near Shutlanger. Work is now proceeding north-eastward from the most westerly working, west of the Blisworth road, near Easton Neston.

The cover ranges from nil up to 35 feet, the working-face having now reached the outcrop of the Great Oolite Limestone. The full thickness of the ironstone worked varies between 10 feet and 12 feet.

The face of the present working, known as Clay-pit Quarry, shows:—

	Ft.	
Great Oolite Limestone—		
Limestone ... ... up to about	8	
Upper and Lower Estuarine Series—		
Blue clay ... ... 2 ft. to	4	
Sand, about	13	35 ft.
'*Variable Beds*'—		
Sandstone, up to about	10	
Northampton Ironstone—		
Ironstone ... ... 10 ft. to	12	

The ironstone, oolitic, is partly brown and partly green, with 'box-structure' and cellular weathering ending abruptly upwards at the overlying sandstone.

[1] From the Ministry of Munitions.

So far the ironstone has been worked entirely opencast, but underground mining is contemplated. The cover is removed by steam-navvy, the ironstone by hand. Average analyses[1] of the ironstone show:—

Monthly average analyses in 1915.

—	Raw Ore. I.		Raw Ore. II.		Calcined Ore. III.		Calcined Ore. IV.	
	As received	Dried.	As received	Dried.	As received	Dried.	As received	Dried.
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Iron	33·01	38·70	34·88	39·10	38·21	40·10	40·39	41·60
Silica ...	12·20	14·30	8·56	9·60	11·72	12·30	13·01	13·40
Lime ...	3·24	3·80	4·01	4·50	4·29	4·50	4·27	4·40
Phosphorus...	1·00	1·17	1·03	1·15	1·27	1·33	1·17	1·21
Moisture ...	14·70	—	10·80	—	4·70	—	2·90	—

Some prospecting has been done in the neighbourhood beyond the actual working-area. There is no reason to doubt that workable ore persists underground northward as far as the Gayton workings, on the east side of the railway. But much of this may be in the green carbonate state and at too great a depth for opencast working. A boring about one-third of a mile north-east of the present working-face, and about 300 yards east of the road near the Reformatory, failed to reach the ironstone at a depth of 80 feet.

[1] From the Towcester Mineral and Brick Co.

CHAPTER VII.

MISCELLANEOUS JURASSIC AND LATER IRON ORES.

Yorkshire. By G. W. Lamplugh.

CRETACEOUS ORES.

Kirby Underdale, East Yorks. (One-inch Geol. map, N.S. Sh. 63; 6-inch map, Yorks. Quarter-Sheet 159 N.E.) At the western edge of the Yorkshire Wolds E.N.E. of York, a patch of ferruginous sandrock emerges from beneath the Chalk at the head of Scotten Dale, a deep coombe 1 mile east of Kirby Underdale. The bed appears to be only 3 or 4 feet thick where first seen in the sides of the coombe, but thickens rapidly eastward to 12 or 15 feet before passing out of sight beneath the Chalk, and may become still thicker underground. It is a coarse-textured rusty-red semi-coherent rock, composed partly of sand-grains and partly of oolitic grains and flaky particles of iron-oxide. A sample collected many years ago, and recently analysed[1], gave, in the dry rock:—Iron, 27·60 per cent. and silica, 38·15 per cent. An analysis made in the Chemical Laboratory of the Geological Survey from samples collected at the outcrop in 1917 gave the following results.

Analysis of ferruginous Sand from Scotten Dale. March, 1919.

Lab. No. 600.				*Sample dried at* 212° *F.*	
	Per cent.				Per cent.
Fe_2O_3 ...	41·65	=	Iron		29·16
SiO_2	37·66				
CaO	2·47				
P_2O_5	1·56				
S	·04				
Insoluble residue			...	...	39·25

It is stated in the memoir on the district[2] that the rock has been "tried as an ironstone but without success." If means should be devised for cheaply separating the sand-grains from the iron-grains in this rock and others of the same character (p. 228) the deposit may be yet found to possess economic value.

The Scotten Dale ironsand is not continued southward, but the band of Red Chalk which forms the basement-bed of the Chalk throughout the Wolds has in this district a conglomeratic base, rarely more than a few inches thick, in which worn lumps of ironstone occur plentifully.[3] Farther south, thin lenticles of ironstone are developed locally at this horizon, as described below.

Goodmanham (One-inch Geol. map, N.S. Sh. 72: 6-inch map, Yorks. Quarter-Sheet 194 S.W.). This place is 12 miles S.S.E. of Kirby Underdale and 1½ mile E.N.E. of Market Weighton. The base of the Red Chalk is exposed here in an excavation at the

[1] We are indebted to Mr. E. O. Forster Brown for particulars of this analysis.

[2] 'Geology of the Country N.E. of York and S. of Malton.' (*Mem. Geol. Surv.*), 1884, p. 25.

[3] *Ibid.*, p. 26.

rifle-butts alongside the railway—Market Weighton to Beverley, and contains thin tabular layers of ironstone, associated with ferruginous marl and ironstone-breccia, as follows:—

Lower part of section at Rifle Butts near Goodmanham.

	Ft.	Ins.
White chalk with a pink band ... ... seen, about	20	
Yellowish chalk. ... ... about	1	0
Deep-red gritty chalk, containing in the lower part, lumps and tabular masses of hard ironstone. 2 to 6 ins thick	1	0
Soft blotchy red and yellow ferruginous marl or decomposed ironstone, seen to	0	7

Analyses of the tabular bands and the ferruginous marl, made in the Chemical Laboratory of the Geological Survey, yielded the following results. It will be seen that the tabular layers are of high quality; but the quantity obtainable would be small.

Analyses of ironstone bands and marl at base of Red Chalk, Goodmanham Rifle Butts.
Samples dried at 212° F.

	Ironstone Band, Lab. No. 601. Per cent.	Ironstone Band. Lab. No. 602. Per cent.	Ferrug. Marl. Lab. No. 603. Per cent.
Fe_2O_3 ...	75·50	67·50	37·50
SiO_2... ...	6·53	7·08	13·06
CaO... ..	·55	4·62	16·45
P_2O_5 ...	·75	·75	1·04
S	·04	·05	·03
Iron ...	52·85	47·25	26·25
Insoluble residue	7·37	8·40	16·48

Lincolnshire and Borders. By C. B. Wedd.

JURASSIC ORES OF MINOR IMPORTANCE.

These ores, on account of their poor quality or expense of working, have been worked only for a short time, if at all:—

Great Oolite.—Overton ironstone: bands of ironstone-balls in Great Oolite Clay at Overton (Hunts.), south of Peterborough (*see* table, p. 141).

Upper Estuarine Series.—Ironstone at Ryhall Heath (Rutland): at base of clays over-lying Lincolnshire Limestone (*see* table, p. 141).

Lower Lias.—Pecten Ironstone; at top of Lower Lias clays in North Lincolnshire (*see* general section, p. 71).

Pecten Ironstone.

The Pecten Ironstone of North Lincolnshire consists at the surface of ferruginous ooliths in a calcareous or marly matrix. From the Frodingham district southward a little beyond Kirton Lindsey it has a thickness of 4 feet or a little more, but is not considered of economic value as an ore.[1] It is said, however, to have been dug as such near West Halton,[2] north of Frodingham and Scunthorpe.

[1] J. Dalgliesh and R. Howse, 'Some Remarks on the Beds of Ironstone occurring in Lincolnshire,' *Trans. N. of Eng. Inst. Min. & Mech. Eng.*, vol. xxiv (1874–5), p. 27.

[2] 'Geology of North Lincolnshire' (*Mem. Geol. Surv.*), 1890, p. 43.

Ironstone at the base of the Upper Estuarine Series.

At Ryhall Heath, $3\frac{1}{2}$ miles north of Stamford, this ironstone forms the flat surface of the ground for some distance, and has been dug at intervals along the north side of the road to Pickworth for nearly a mile. It consists in its weathered state of a cement of ferric oxide enclosing sand-grains, with crusts and joint-fillings of rich brown limonite. It shows no oolitic structure in that state, and is apparently an argillaceous and siliceous ore fairly rich in iron. No evidence was found of its full thickness, but 1 foot of it was visible in places. It seems to be merely a local deposit, of doubtful economic value. Its exploitation has been considered, but the project was abandoned on realizing that the ore was not, as had been supposed, the Northampton Ironstone.

In Northamptonshire this ironstone has a wide distribution as a band of nodular iron-ore ('ironstone junction-bed') seldom much more than 1 foot in thickness, but worked in ancient times.[1] It yields a good quality of iron, but does not pay to work.[2]

Ironstone-bands of the Great Oolite Clay.

Near Overton Longville, south of Peterborough, "the late Marquis of Huntly commenced digging the ironstone-balls, which form four bands in the midst of the dark-blue clays [Great Oolite Clay]. The ironstone in the upper bands was soft and of a dark-brown colour, owing to weathering action, but the lower bands were of a greenish-white colour, and unoxidised, and every gradation between these two varieties occurred. The ironstone is said to have been of good quality, and between 100 and 200 tons of it were sent to Wellingborough to be smelted. Its exploitation was soon abandoned, owing to the quantity of material which had to be removed to obtain the nodules of ironstone."[3]

CRETACEOUS ORES OF LINCOLNSHIRE.

Claxby Ironstone.

(One-inch New Series Ordnance maps 89, 90, 103. Old Series Geological, 86, 83.)

The Claxby Ironstone occurs at the base of the Tealby Clay, and immediately above the Spilsby Sandstone, all three deposits belonging to a local development of the Lower Cretaceous Series. The following section[4] represents the general sequence and the thickness of the strata in the neighbourhood of Nettleton and Claxby, within the main area of this ironstone-formation (*see* map, Pl. V).

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[1] 'Geology of Rutland' (*Mem. Geol. Surv.*), 1875, pp. 112, 189.

[2] B. Thompson, *op. supra cit.*, p. 476.

[3] Geology of Rutland' (*Mem. Geol. Surv.*), 1875, p. 217; quoted in 'Jurassic Rocks of Britain,' *ib.*, vol. iv, 1894, p. 416.

[4] Based on J. W. Judd's section in 'Additional Observations on the Neocomian Strata of Yorkshire and Lincolnshire,' *Quart. Journ. Geol. Soc.*, vol. xxvi, 1870, p. 331.

Section of Upcast Shaft, Acre House Mine.

	Ft.	Ins.
Soil	2	6
[*Upper Cretaceous*]—		
White chalk [*Lower Chalk*] ... ... 9 to	10	0
Beds of yellow clay and red marly chalk [*Red chalk*] ...	10	0
Red sand [*Carstone*]	10	0
[*Lower Cretaceous*]—		
Limestone rock, hard and blue-hearted [*Tealby Limestone*]	14	0
Blue clay [*Tealby Clay*]	40	0
Ironstone, soft and earthy above, solid and finely oolitic below (only the lower part is worked) [*Claxby Ironstone*] ... ... 13 to	14	0
Coarse greenish-white sands ,in places indurated into hard sandstone-rock [*Spilsby Sandstone*] ... ... 6 to	7	0
[*Jurassic*]—		
Very dark-coloured, highly bituminous, shaly clay. A thin bed at the top is remarkable for its highly inflammable character and greatly resembles the Kimmeridge coal of the south of England (*Kimmeridge Clay*) ...	—	

South-eastwards the Lower Cretaceous increases to 230 feet, made up almost entirely of clay, at Skegness, while northward it is overstepped by the Upper Cretaceous, which rests on Kimmeridge Clay at Clixby. Further changes take place within the series, a calcareous and ferriferous bed, the 'Roach,' replacing the upper part or the whole of the Tealby Limestone southward, and from the neighbourhood of Claxby becoming submerged beneath a higher development of clay like the Tealby Clay[1] (*see* Pl. IV, Sect. 2).

The oolitic Claxby Ironstone is sharply separated from the Spilsby Sandstone below, but, becoming softer and more argillaceous upward, passes gradually into the Tealby Clay above, the lower part of which usually contains numerous brown ferruginous ooliths.

Palæontologically it is included with the Spilsby Sandstone in the zone of *Belemnites lateralis* (which belemnite occurs abundantly in the ironstone), while the Tealby Clay belongs to that of *B. jaculum*.[2] A highly characteristic fossil of the ironstone is the large *Pecten cinctus*, Sow.[3]

Where the Claxby Ironstone is present, the strata on the whole have an eastward dip, masked locally by undulations with west-and-east axes (*see* Pl. IV, Sect. 2).

The ground rises somewhat steeply eastward in the Cretaceous escarpment, but reaches its maximum elevation quite close to that escarpment, the highest point in Lincolnshire (548 O.D.) lying not far from the Acre House mine. Thence the ground falls away to the east, on the whole gradually and at much the

[1] *See* A. Strahan, 'Notes on the Relations of the Lincolnshire Carstone,' *Quart. Journ. Geol. Soc.*, vol. xlii 1886, pp. 486–492.

[2] G. W. Lamplugh, 'On the Speeton Series in Yorkshire and Lincolnshire,' *Quart. Journ. Geol. Soc.*, vol. lii, 1896, pp. 199–208.

[3] For lists of fossils of the Claxby Ironstone, *see* H. Keeping, 'On some Sections of Lincolnshire Neocomian,' *Quart. Journ. Geol. Soc.*, vol. xxxviii, 1882, p. 241: 'Geology of Lincoln' (*Mem. Geol. Surv.*), 1888, pp. 102–3.

same rate as the general dip of the beds. Consequently, while the Claxby Ironstone in the escarpment rapidly passes under thick cover, the depth to it does not increase appreciably for a considerable distance eastward in that neighbourhood.

This ironstone, representing a similar ore worked at several places in North Germany, in the corresponding 'Hils' formation,[1] is not found in the equivalent Speeton Clay Series of Yorkshire and in Great Britain is confined to a part of Lincolnshire.

It is known to be continuous at its outcrop along the western edge of the Lincolnshire Wolds, from Audleby north of Caistor, where it disappears northward under the Upper Cretaceous beds, to Donington-on-Bain, a distance of about 22 miles in a south-easterly direction (*see* map, Pl. V; also Pl. IV, Section 2). But it is by no means certain that it maintains a commercial quality throughout that distance. Thence farther along the Lower Cretaceous escarpment to the neighbourhood of Hundleby near Spilsby, no development of ironstone is known at this horizon. But at Hundleby and in its immediate neighbourhood a similar bed of iron-ore, apparently of no economic value, is found at the base of the clay that overlies the Spilsby Sandstone. That ironstone, however, has been shown to belong palæontologically to a slightly lower horizon than the Claxby Ironstone, and is not likely to be continuous with it. A poor representative has been proved in the same stratigraphical position at Willoughby, near Alford, at a depth of 214 feet,[2] but none was found in this position at Skegness, or Dalby, north of Spilsby.[3]

The Hundleby Ironstone may reasonably be neglected as an economic asset. The Claxby Ironstone, on the assumption of its continuity from the roughly convex outcrop between Audleby and Donington-on-Bain eastward underground as far as a straight line joining these points, would extend over an area of a little more than $1\frac{1}{2}$ square miles, in which almost the whole extent of it would require mining. At an assumed average of 6 feet of workable ore, this area would give somewhere about 15,000,000 tons, but the continuity of good ore is not certain. On the other hand, the bed may extend considerably farther eastward beyond the arbitrary limit here assumed.

In many cases only the lower part of the bed is fit for use as an ironstone. The average thickness of the ironstone as proved in four borings at Nettleton Top Farm, south of Nettleton, is 8 feet 6 inches; in six outcrop-trials in the same neighbourhood, 7 feet 8 inches.[4] At the Acre House Mine a thickness of 14 feet for the whole ironstone-bed contained on the average only

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[1] J. W. Judd, 'Additional Observations on the Neocomian Strata of Yorkshire and Lincolnshire,' *Quart. Journ. Geol. Soc.*, vol. xxvi, 1870, p. 326.

[2] A. J. Jukes-Browne, 'On some recent Borings through the Lower Cretaceous Strata of East Lincolnshire,' *Quart. Journ. Geol. Soc.*, vol. xlix, 1893, p. 469.

[3] 'Water Supply of Lincolnshire' (*Mem. Geol. Surv.*), 1904, pp. 87, 156, 185; 'Thicknesses of Strata' (*Mem. Geol. Surv.*), 1916, plate facing p. 90.

[4] From information by the Appleby Iron Co., Ltd.

6 feet 6 inches of workable ore.[1] A boring 600 yards from the outcrop of the ironstone at Claxby gave the following results[2] :—

	Ft.	Ins.
Sand, washed down : superficial deposit [? partly *Carstone*] ...	30	0
Limestone [Tealby Limestone]	16	0
Blue clay [Tealby Clay]	40	0
Grey rock mixed with ironstone	5	0
Ironstone / Clay / Ironstone } [Claxby Ironstone Bed]	3	0
	1	0
	5	0

Total thickness of ore 8 feet.

A boring recently made by the Ministry of Munitions (Department for Development of Mineral Resources) on the north side of Donington Station in search of oil-shale commenced in the Lower Cretaceous, and proved the following section, as determined by Mr. J. Pringle :—

Section of Bore-hole near Donington-on-Bain Station.

		Ft.	Ins.
Superficial Deposits ...	Reddish soil, chiefly composed of weathered ironshot marl	0	6
Tealby Clay	Blue clay	43	6
Claxby Ironstone ...	Pale brown ironshot marl, shelly in places, with small brightly polished brown ooliths, more or less closely aggregated	4	0
Spilsby Sandstone ...	Sand (no cores)	13	0
	Loose fine-grained quartz-sand, somewhat muddy towards base	30	6
	Hard coarse quartzose sandrock, slightly glauconitic, with some black phosphatic grains	0	6
	Loose fine-grained quartz-sand, with some hard indurated lumps near base	36	0
	Dark grey shelly calcareous sandstone, full of rounded blackish phosphatic nodules, and derived fossils in bottom layers	1	0
Kimmeridge Clay ...	... ...	—	

From the Claxby Ironstone in this bore-hole a 4-foot core was drawn, but possibly the softer upper part of the ironstone-bed was included in the Tealby Clay, from which no cores were obtained. It is noteworthy that the thickness of Spilsby Sandstone here proved is unusually great.

The Claxby Ironstone consists of a more or less close aggregation of ferriferous ooliths, usually with brightly polished surfaces, brown in the oxidized, but blackish-green in the unweathered stone, within a light-grey marly matrix, which weathers yellowish-brown. The upper part of the stone is often softer and more argillaceous than the lower and better part. The Claxby ore is essentially a siliceous ore in its better varieties, as compared with the Frodingham and the Marlstone of Mid Lincolnshire. Its lime-content seems to depend upon the amount and nature of the matrix, for a rough chemical test of the grey

[1] J. W. Judd, *op. supra cit.*, p. 330.

[2] From the North Lincolnshire Iron Co., Ltd.

marly matrix from Donington showed a high percentage of both silica and lime, with a much less amount of iron; while separate analyses of the matrix and the ooliths of the ore from Claxby showed little lime in the matrix, and the following composition of the ooliths[1]:—

	Per cent.
Silica	5·34
Sesquioxide of iron	76·76
[= Metallic iron, about 53·73.]	
Moisture	16·17

The interstitial matrix of variable composition constitutes a considerable part of the bed, and the richness of the ore is dependant upon the closeness with which the ooliths are aggregated. The better and less calcareous varieties are regarded as suitable for mixing as a siliceous ore with the highly calcareous Frodingham Ironstone.

The following partial analyses show the average composition of the raw ore in the neighbourhood of Nettleton and Claxby:—

	1. Average of 4 trials (outcrop) at Nettleton Top Farm (sampled and analysed by the Appleby Iron Co., Ltd.)	2. Average of several trials at Nettleton, and Claxby.	3. Average sample from Claxby (N. Lincs. Iron Co.)
	Per cent.	Per cent.	Per cent.
Iron, as received	29·60	26·63	25·60
Iron, dried at 100° C.	36·48	31·61	30·10
Insoluble, as received ...	16·80	Silica 17·56 Alumina 3·15	18·06 6·94
Lime, as received ...	2·51	4·45	5·71
Moisture	18·18	16·53	14·80

Kendall gives the following complete analysis[2]:—

"*Analysis of Claxby Ironstone from Acre House Mine.*

	Per cent.
Water at 212° Fahr.	5·68
Water, combined	10·48
Peroxide of iron	52·86
Oxides of Alumina [*sic*] and Manganese	6·45
Lime	2·00
Magnesia	1·57
Phosphoric acid	·24
Sulphuric acid	Trace.
Carbonic acid	2·94
Insoluble silicious matter	17·26
Total	99·48
Metallic iron	37·00."

The Claxby Ironstone was known to the Romans as a source of iron, as is proved by the association of iron-slag, calcined ore and charcoal with Roman pottery,[3] but all knowledge of it seems

[1] Analysis by M. Staniland quoted in 'Geology of Lincoln' (*Mem. Geol. Surv.*), 1888, p. 95.

[2] 'Iron Ores of Great Britain,' p. 250. 'The sample giving these results was in a highly air-dried condition.' The analysis was presumably made on an old hand-specimen, not on an average sample of fresh ore.

[3] Judd, *op. supra cit.*, p. 329.

to have been lost in later ages. In recent times it has been worked on a small scale at Hundon, north of Caistor, and at Tealby.[1] At the Acre House Mine, which began working in 1868, the output amounted in fourteen years to about 390,000 tons, and was sent, according to Judd,[2] to Leeds for mixing with Coal-measure [' clay-band '] ore. It seems to have been used to some extent at Frodingham[3] also. It was carried by private railway from the mine 1½ miles to Holton-le-Moor Station, on the Market Rasen branch of the M.S. and L. Railway (now G.C.R.).

The annual output of Claxby Ironstone[4] from 1868 to 1881, since which date that ironstone has scarcely been worked at all, was:—

Year.	Output in tons.	Year.	Output in tons.
1868	5,000	1875	37,102
1869	32,500	1876	51,300
1870	31,500	1877	9,625
1871	36,000	1878	18,426
1872	62,653	1879	323
1873	70,000	1880	27,500
1874	885	1881	7,378

The use of this ore in mixture with the Frodingham ore has been considered in recent years, but expense of working and transport has until lately been regarded as prohibitive.

A few attempts have been made, apparently without success, to find profitable ore in this bed by sinking shafts in other parts of the district: one shaft was sunk on the Tealby Limestone, near Risby Hall, another 2⅓ furlongs south of Otby on the Carstone, and a third, not completed, on the Chalk east of Otby.[5]

Roach Ironstone.

An upper bed of so-called ironstone, the 'Roach,' apparently always of poor quality, is found above the Tealby Limestone from Normanby-on-the-Wold south-eastward; and in the southern part of the Wolds passes down into a ferriferous limestone at the same horizon as the Tealby Limestone. Above the Tealby Limestone the Roach consists of soft marl with numerous ironstone ooliths and occasional hard bands of ironstone-rock. Levels were once driven into this a quarter of a mile east-north-east of Otby, but the ore was stated not to be worth extraction.[6]

Compact ferruginous bands occur in the Roach at Langton and Skendleby, near Spilsby, but on analysis yielded a low percentage of iron.[7]

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[1] Kendall, *op. cit.*, p. 248.

[2] *Op. supra cit.*, p. 330.

[3] *See* R. Meade, 'Coal and Iron Industries of Great Britain,' 1882, p. 563.

[4] 'Mineral Statistics of the United Kingdom' (*Mem. Geol. Surv.*).

[5] 'Geology of Lincoln' (*Mem. Geol. Surv.*), 1888, p. 95.

[6] *Op. cit.*, p. 100.

[7] 'Geology of East Lincolnshire' (*Mem. Geol. Surv.*), 1887, p. 134.

Wiltshire. By J. Pringle.

JURASSIC ORES.

Westbury (One-inch New Series Ordnance map 281; Old Series Geological, 14; six-inch Wilts. 44 N.E.).—The Westbury iron-ore occurs at the top of the Corallian rocks. It was first worked about the year 1856, and the annual output till 1885 varied between 5,000 and 105,939 tons. Since 1885 the output has not been separately given in the returns, except for the year 1892, when it was 70,866 tons.

The Corallian rocks, as developed in the neighbourhood, consist of marly oolitic and pisolitic limestones, with bands of brown and blue sands and marls. Their uppermost part is formed by brown and greenish-brown oolitic ironstone. The aggregate thickness of the Corallian was proved to be slightly over 100 feet in a well sunk at the ironworks.[1] In several of the disused working-faces, the following details of the uppermost beds of the series may be traced:—

		Ft.	Ins.
	Superficial deposits resting on a variable thickness of Kimmeridge Clay ... ... 1 ft. to	20	0
Upper Corallian.	Brown and greenish-brown finely oolitic iron-ore with numerous layers of *Ostrea deltoidea* J. Sow., etc. ...	1	6
	Finely oolitic brownish-blue ironstone, well-bedded at top	3	0
	Shelly oolitic ironstone	1	0
	Finely oolitic brownish-blue ironstone with thin shelly layers	6	0
	Light greenish-grey, buff, and brown sands with seams of clay ... ... 4 ft. to	10	0
	Blue and buff marly oolitic and pisolitic limestones with layers of oolitic marl and clay ... ... 10 ft. to	12	0
	Fine false-bedded oolitic limestone, buff at top and bluish towards base ... ... 8 ft. to	10	0

The productive outcrop of the ironstone extends as a narrow belt running N.E. to S.W. for a distance of about $2\frac{1}{2}$ miles (*see* Fig. 12, p. 217), the beds dipping to the S.E. at an angle of 4°. To the south it disappears under the Gault, and to the north it is terminated by a fault which brings up Oxford Clay. The same beds reappear on the north side of the fault, about 2 miles to the N.E., and extend thence for some miles, but the ironstone, though present according to Mr. G. C. Greenwell,[2] is much reduced in thickness.

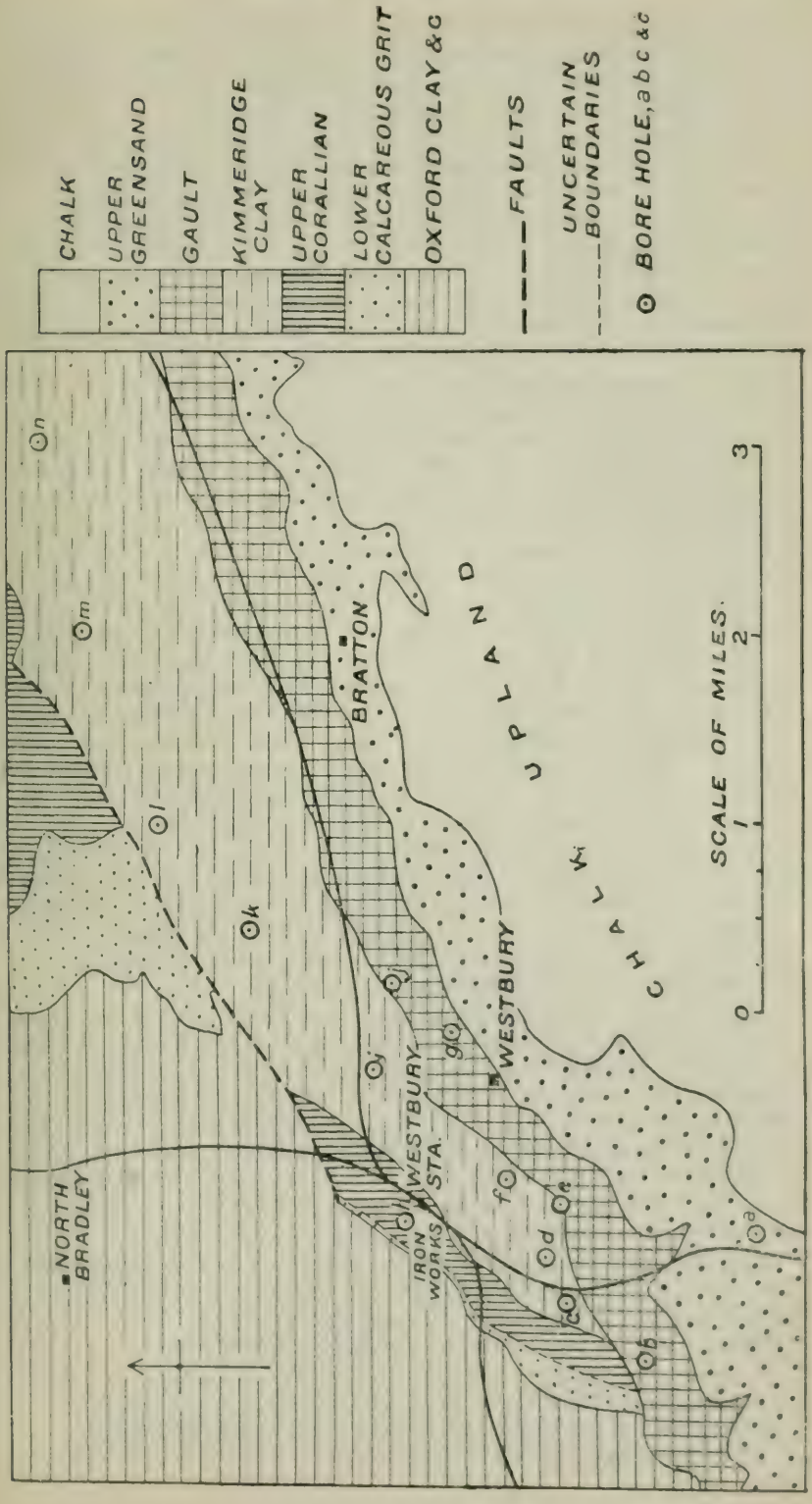
The thinning-out of the ore in a north-easterly direction has also been shown by borings which were made to determine its extension beneath the newer formations. The holes were bored at intervals on sites (shown on Fig. 12) approixmately parallel to the strike of the Corallian deposits. For the following details we are indebted to Mr. W. J. Love.

At Dilton (Borehole *a*, Fig. 12) the ore is 9 feet thick, beneath a cover of 283 feet of Gault and Kimmeridge Clay; at Dilton Marsh, around Penleigh, Eden Vale, and Frogmore (Boreholes *b-j*), it averages 10 feet, beneath a varying amount of

[1] Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. v, 1895, p. 111.

[2] G. C. Greenwell, 'On the ironstone of Wilts. and Somerset,' *Proc. South Wales Inst., Eng.*, vol. i, 1859, pp. 307—323.

FIG 12.—*Sketch-map of the Westbury District.*



overlying beds; at Fulling Bridge on the Heywood Estate, and near Dunge Farm (Boreholes *k* and *l*) it swells out to 16 feet in thickness, but north-east of this point in the trial-holes of Horsecroft and Dairy House Farms (Boreholes *m* and *n*), it diminishes to 3 and 2 feet. Its full extent in the direction of dip has not been determined, but it is highly probable that the seam suffers attenuation as the distance from the outcrop is increased. According to Blake and Hudleston, "a well sunk about halfway between the town [Westbury] and the railway station, after passing through about 50 feet of Kimmeridge Clay, showed that the ore had diminished to a thickness of 2 feet."[1] So rapid an attenuation of the ore, however, is unlikely, in view of the thickness proved in the Eden Vale borehole.

In the weathered outcrop the ore is reddish-brown and in this condition is known commercially as 'brown ore,' but under cover it becomes a bluish-green carbonate with red rusty joints, and is known as 'blue ore.' In both conditions it is mainly composed of small shining grains of iron resembling millet-seed, densely packed together in a brownish or dark yellowish-green matrix "Under the microscope the ironstone, as noted by Mr. Teall, shows reddish-brown oolitic grains with concentric structure in a dark yellowish-green matrix. The matrix contains a large number of colourless crystalline and detached grains of calcite of fairly uniform size, and much smaller than the oolite grains. The nuclei of the larger oolite grains are in many cases broken fragments of other grains. The residue after treatment with hydrochloric acid, consists of siliceous balls (soluble in a solution of caustic potash) and of minute angular fragments of oligoclase and quartz."[2] The ironstone is highly fossiliferous, and yields great quantities of shells belonging to large molluscs, such as ammonites, *Ostrea*, *Lima*, *Pecten*, etc. The shelly layers are, however, rejected. Hudleston[3] has pointed out that where there is an abundance of large shells of Monomyaria in Mesozoic ironstone, "there is often a large charge of phosphorus in the ore, due in part at least to the decomposition of the animal matter of these molluscs and associated organisms."

Most of the brown ore appears to have been worked out along the outcrop, but in the Heywood opening on the S.E. side of Ham Lane, 700 yards S.S.W. of Heywood Church, a small area showing about 11 feet of brown finely oolitic ore, which had previously escaped attention, is being quarried. The ore is drawn on rails by a light locomotive to works adjoining the blast-furnaces, where it is dried on flat iron plates. It is then screened and dispatched in covered waggons to London, Liverpool, Birmingham, Swansea, etc., where it is used as an oxide for gas-purification.

The blue ore is well-exposed in numerous old working-faces, but is not worked at present. Owing to the increasing thickness of cover in the direction of dip, mining will have to be resorted to when the area proved in the boreholes is worked.

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[1] *Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, p. 284.

[2] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. v., 1895, p. 324.

[3] *Proc. Geol. Assoc.*, vol. xiii, 1893, p. 138.

The chemical composition of the two kinds of ore has been described repeatedly. The following details of recent analyses were kindly provided by the manager, Mr. W. J. Love.

Brown Ore.

	Per cent.
Peroxide of iron	42·41
Protoxide of iron...	7·86
Insoluble siliceous matter	16·00
Lime	5·90
Magnesia	2·13
Manganous oxide	·22
Sulphuric acid ... ... (Sulphur 0·265).	·666
Phosphoric acid ... ... (Phosphorus 0·481).	1·103
Alumina	4·70
Loss on ignition	19·20
	100·189
Metallic iron	35·78

Blue Ore.

	Raw. Per cent.	Calcined. Per cent.
Peroxide of iron	42·60[1] ...	60·90
Silica	11·36 ...	16·31
Sulphur...	0·314 ...	0·45
Phosphorus	0·469 ...	0·67
Lime	5·280 ...	7·60
Magnesia	1·490 ...	2·14
Alumina	7·850 ...	11·27
Loss on calcination	30·350 ...	—
	99·713 ...	99·34
Metallic iron...	29·68 ...	42·63
Phosphoric acid	1·074 ...	1·54

Vanadium was noted in an analysis made by Mr. E. Riley.[2] According to Kendall,[3] "the average specific gravity of the brown ore is about 2·5, of the blue and green ore 2·6, and their respective porosities are about 25 and 14 per cent."

The reserves of brown ore in the crop-workings are small, but the unworked area proved by borings amounts to nearly 1,500 acres. With an average thickness of 11 feet, an amount of 26,000,000 tons of reserves more or less developed is estimated, with probable additional reserves amounting to 22,500,000 tons.

Sturminster Newton (One-inch New Series Ordnance map 313; Old Series Geological, 18; six-inch Dorset, 13 N.E.).—Near Sturminster Newton, about 22 miles south of Westbury, Woodward[4] noted the following section in a lane cutting near Hole leading to Banbury Common:—

	Ft.	Ins.
Kimmeridge Clay—		
Clay with a sandy layer; nodular bed at base	3	0
Corallian—		
Ferruginous beds like the oolitic iron-ore of Abbotsbury and Westbury, with a band of blue-hearted sandy limestone	10 to 15	0

[1] It would appear that this must include much protoxide of iron.
[2] *Journ. Chem. Soc.*, vol. ii. 1864. p. 21.
[3] 'Iron Ores of Great Britain and Ireland.' 1873. p. 247.
[4] 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. v, 1895, pp. 102–103.

He remarks that "the ferruginous beds would be worth opening up more clearly, so that their economic value might be tested. The general section in the area compares well with that of Abbotsbury." No trials appear to have been made, and in 1917 the section was no longer open. The Abbotsbury occurrence is described on pp. 221-3.

LOWER CRETACEOUS ORE.

Seend (Lower Greensand).—The occurrence of iron-ore at Seend, near Devizes (*see* map, Fig. 1), attracted attention about 1855, and from that time until 1861, 77,984 tons of 'brown hematite' were raised. In the ten years following there was a period of inactivity, but between 1871 and 1874 a total of 86,443 tons was quarried. From 1874 until recently, operations have been in abeyance. The iron appears to have been smelted on the spot, and the sites of the furnaces are still to be seen.

The deposit, which is mainly a brown ferruginous sand, occurs as an outlier of Lower Greensand, slightly over a mile in length, and about 580 yards broad at its greatest width. Much of it is occupied by the village of Seend. The beds are nearly horizontal, and rest unconformably on the Kimmeridge Clay. The ironstone occurs in layers of irregular thickness, and frequently forms hard dark brown crusts around patches of soft loosely coherent greenish quartz-sand, which crumbles away and leaves the rock in a cellular condition. Vertical joints are numerous and the majority of them are filled with clay washed-down from the surface. Excellent sections of the ironsand can be seen at the west end of the village, and along the face of the old workings[1] the following particulars of the beds were obtained:—

Old quarries at west end of Seend Village, 920 yards S.S.E. of Seend railway station.

Avon Valley Iron Co., 175, St. Vincent Street, Glasgow.
One-inch New Series Ordnance map 281; Old Series Geological. 14; six-inch map Wiltshire 33 S.E.
Latitude 51° 20′ 53″. Longitude 2° 5′ 24″.

	Ft.	Ins.
1. Crumbly ferruginous sand rock, ... 3 to	5	0
2. Rather coarse quartz-sand with ferruginous matter forming hard dark-brown concretionary crusts around oval patches of more or less incoherent sand ...	10	0
3. Ironsand with platy structure like that of upper bed, with lenticular cindery concretions, about	5	0

North of the school disused quarries, about 30 feet deep, show similar beds of ironstone. The sands probably are not more than 40 feet thick, but are nowhere fully exposed to view. According to J. D. Kendall,[2] the lower beds, for 6 feet above the Kimmeridge Clay, are pebbly and poor in iron. The same conditions were found in a neighbouring road-cutting described by W. Cunnington,[3] where the junction with the Kimmeridge Clay was exposed.

[1] This section has been described in 'The Geology of the Country south and east of Devizes' (*Mem. Geol. Surv.*), 1905, pp. 9–12, 48–49.

[2] 'The Iron Ores of Great Britain and Ireland,' 1893, p. 251.

[3] *Quart. Journ. Geol. Soc.*, vol. vi, 1850, p. 453.

From Mr. Kendall's description it appears that only the crusty partings were used as iron-ore. No analysis of the average run of the ore as worked is available, but he gives (on p. 251) the following analysis of "a piece of the orey part of the deposit" by E. Riley:—

	Per cent.
Peroxide of iron	64·61
Silica	18·02
Alumina	3·85
Lime	0·64
Magnesia	0·20
Phosphoric acid	0·64
Water	11·85
	99·81
Metallic iron	45·22

The average specific gravity of the orey part of the bed is about 2·5, and its porosity varies from 13 to 22 per cent.

The following analysis, made by the Ebbw Vale Company, has been recently published[1]; it is not stated, however, whether it is a bulk analysis or that of a selected portion of the rock.

	Per cent.
Iron	37·6
Silica	27·0
Alumina	5·9
Lime	0·8
Magnesia	1·0
Phosphorus	0·25
Sulphur	0·01

In estimating the reserves of ore at Seend, the area covered is taken as 179 acres of which about 64 acres are occupied by the village. The average thickness is estimated to be 20 feet, and the yield as 2,500 tons per foot per acre. On these figures the probable available reserve is calculated to be 5,500,000 tons.

Dorset. By J. Pringle.

Jurassic Ores.

Abbotsbury (One-inch New Series Ordnance maps, 341, 327; New Series Geological, 341 and Old Series, 17).—The occurrence of oolitic iron-ore at Abbotsbury in Dorset attracted the attention of Sedgwick,[2] and has been subsequently described by many geologists.[3] The ore, however, has been little worked, owing no doubt to the high percentage of silica it contains.

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[1] 'Report on the resources and production of iron-ores and other principal metalliferous ores used in the iron and steel industry of the United Kingdom.' *Depart. of Scientific and Industrial Research*. London, 1917, p. 23.

[2] A. Sedgwick. *Ann. Phil.*, vol. xxvii (Ser. 2, vol. xi), 1826, p. 350.

[3] Accounts of the sections will be found in the following publications:— J. F. Blake and W. H. Hudleston, 'The Corallian Rocks of England,' *Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, pp. 273–275. R. Damon, 'Geology of Weymouth,' 1884. 'Jurassic Rocks of Britain' (*Mem. Geol. Surv.*), vol. v, 1895, pp. 94, 323–325. 'Geology of the Isle of Purbeck and Weymouth,' *ib.*, 1898, pp. 37–40.

The ferruginous bed averages about 20 feet in thickness and extends for a distance of several miles along the outcrop, but the rich part is confined to a synclinal area, in which Abbotsbury is situated. In approaching the village "the presence of iron-ore is first suggested by the deep-red colour of the grit north of Kodden and at Elworth. On the north side of Linton Hill ore was found containing 32–36 per cent. of metallic iron, and from this point it may be traced continuously under the Abbey, up Seaway Lane, along the north side of Stavordale Wood to Fuller's Way, north of the Castle Gardens; here it is well exposed. . . . Thence it may be followed northwards up to the fault, by which it is thrown against Forest Marble."[1] North of the village the ore is definitely limited by the fault mentioned, but eastwards it passes under Kimmeridge Clay, and its extent is not known; south of the village a ferruginous character in the same bed is noticeable, but ore that would be worth working is unlikely to extend beyond St. Peter's Abbey.

The deposit mainly consists of loose, crumbly, reddish-brown oolitic iron-ore with a hard bed of sandstone near the base; the mass is traversed by numerous thin irregular seams of concretionary iron. The pellets or granules of ore are bright and shining, and lie closely packed in a matrix of fine quartz-sand. According to Blake and Hudleston,[2] "the granules, when broken, are seen to consist of a brown exterior shell, which is largely, but not wholly, composed of ferric hydrate, and of an interior filled with a buff-coloured powder much poorer in iron. . . . After treatment with acid there remains a residue presenting a sphere on sphere structure, hollow within, and composed of a uniform subcrystalline material, the greater part being silica." Below the main bed, the rocks contain iron-ore in the form of pellets, but are less rich. In appearance the main seam closely resembles the iron-ore worked at Westbury (*see* p. 216), but it is shown by its fossils to correspond with beds classed elsewhere as part of the Kimmeridge Clay. Most of the fossils occur in the form of brown earthy casts.

Numerous exposures can be found in the lanes on the north and south sides of the village, but the best now available is that seen in the sides of the lane leading from Abbotsbury to Gorwell Gate:—

	Ft.	Ins.
Yellowish-brown ferruginous sand, veined by thin irregular seams of iron ... ... 6 ft. to	8	0
Crumbling reddish-brown rock, full of shining pellets of ore in a matrix of fine quartz-sand. A hard bed of sandstone occurs near the base. Beds traversed by numerous long thin seams of concretionary iron, about... ...	20	0
Dark brown coarse sandrock with ferruginous pellets ...	2	6
Soft yellow-weathering sand	2	0
Dark brownish-green ferruginous sandrock	1	0
Soft yellowish-brown sandstone with hard bands, about...	10	0

[1] 'Geology of the Isle of Purbeck and Weymouth' (*Mem. Geol. Surv.*), 1898. p. 38.

[2] *Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, p. 274.

The available analyses do not suffice to show the average composition of the ore, but the iron-content is likely to be not less than 30 per cent. An old analysis (1860) of a specimen from the road-cutting in the Fuller's Way, north of the Castle Gardens, reads as follows[1]:—

"Sesquioxide of iron	43·97
Silica	42·60
Magnesia	1·40
Lime	Trace.
Common salt	,,
Water	11·88
	99·85"

"This is equivalent to about 34–35 per cent. of iron in the calcined ore."

The following analysis of the granules apart from the matrix is given by Blake and Hudleston[2]:—

	Per cent.
Moisture	1·21
Constitutional water	11·29
Ferric oxide	73·57
Alumina and soluble silica	4·17
Lime	1·60
Magnesia	1·41
Insoluble in HCl	5·53
Organic matter, carbonic acid and loss	1·22
Phosphoric acid	Trace.

The area occupied by the ore, apart from its unproved extension beneath Kimmeridge Clay, is about 256 acres, 60 of which are occupied by the village of Abbotsbury. The average thickness of ore in this area is estimated at 20 feet, and the probable contents of this ironfield are calculated to amount to 11,500,000 tons.

Kent. By G. W. Lamplugh.

JURASSIC ORES PROVED IN DEEP BORINGS.

Upper Corallian.—In boring and sinking operations in connection with the development of the deep-seated coal-field in East Kent, ferruginous strata have been found at three or four separate horizons in the Jurassic rocks, and in one case at least the ore is sufficient in quantity and quality to be of economic value. The particular bed referred to occurs in the upper part of the Corallian series, nearly at the same horizon as the ore of Westbury, Wilts (*see* p. 216) which it also resembles in structure and chemical composition. It is best developed in the neighbourhood of Dover, and was passed through in the shafts of the colliery, west of Shakespeare's Cliff, which gave the following section through the series[3]:—

[1] 'Geology of the Isle of Purbeck and Weymouth' (*Mem. Geol. Surv.*), 1898. p. 40.

[2] *Quart. Journ. Geol. Soc.*, vol. xxxiii. 1877, p. 275.

[3] For full details of the whole of the Jurassic section, *see* 'On the Mesozoic Rocks in some of the Coal Explorations in Kent' (*Mem. Geol. Surv.*), 1911, Chap. II.

Dover Colliery section, to base of Corallian.

Surface at 44 feet above H.W.M.			Thickness.	Depth.
			Ft.	Ft.
Chalk, etc., and Gault		...	301	301
Lower Greensand and Wealden		...	215	516
Kimmeridge Clay		...	44	560
		Ft.		
Upper Corallian.	Oolitic limestone	8	96	656
	Calcareous claystone, clayey oolitic limestone, muddy grit, etc.	18		
	Grey and brown clay, sprinkled and streaked with 'ironshot' grains	7		
	Iron-ore bed: shining brown globules of iron thickly crowded in a loamy matrix, with some claystone concretions ...	16		
	Hard concretionary rock-band, with globules and worn fragments of iron-ore and quartz-grit, etc.	0¼		
	Sandy clay, with glauconite, etc.	7¾		
	Laminated clayey sand-rock	1		
	Calcareous claystone-bands, with thick partings of sandy clay	12		
	Blue and grey clay with shelly and silty layers	26		
Corallian Limestones		...	126	782
Lower Corallian (clays, claystones, marlstones, etc., sparingly 'ironshot' in places)		...	88	870

An average analysis[1] of 15 feet of the ore-bed in the above section from samples taken foot by foot, showed:—in the raw ore:—water, 10·16 per cent.; metallic iron, 32·94 per cent.; silica, 14·96 per cent.; and in dried ore:—lime, 8·91 per cent. It is noteworthy that although the bed is so deeply buried and cannot have been exposed to atmospheric weathering at any time since its deposition, most of the iron that it contains is in the fully oxidized or ferric condition, and is, in fact, a dimonite.

Borings have proved that the ore-body tends to deteriorate, both in thickness and quality, in its landward extension from Dover. At Farthlingloe, about a mile north of the Dover shafts, it was found to have nearly the same thickness as in the above section; but at Abbotscliff, 2 miles W.S.W. of the shafts, it was diminished to about 8 feet; and at Folkestone, 4 miles W.S.W. of the shafts, it had degenerated into a 5-ft. band of brownish marlstone sprinkled with iron-ore globules and lumps. Inland, at Lower Standen, 3½ miles W. of Dover, it was represented only by streaks of 'millet-seed' ore, a few inches thick, among brown marly clay; and at Elham, 7½ miles W.N.W. of Dover, it appears to have thinned out entirely, though at Brabourne, 14 miles W. of Dover, it is again represented by a ferruginous 'millet-seed' band, 3 feet thick.[2]

In the promising area around Dover the ore is rendered accessible by the colliery shafts. The tract in which it is considered of workable value is estimated to cover about 6 square miles, with an average thickness of 9 feet of good ore. This represents approximately one hundred million tons of ore.

[1] We are indebted to Mr. E. O. Forster Brown for analyses and much other information respecting the ore-bed.

[2] *See* memoir *supra cit.*, p. 42.

An analysis of the ore from one of the boreholes gave the following results:—

			Per cent.
Moisture in raw stone...			9·63
Dry Ore.	Per cent.		
Fe_2O_3	38·71	= Iron ...	32·20
FeO	6·56		
SiO_2	13·77		
Al_2O_3	4·77		
MnO	·167	= Manganese...	·129
CaO	11·18		
MgO	2·92		
P_2O_5	·917	= Phosphorus .	·401
S	·055		
As_2O_5	·010	= Arsenic ...	·007
CO_2, H_2O, etc.	20·13		
	99·189		
Loss on calcining			19·40

Kellaways Rock.—Several of the Kentish borings passed through a lower ferruginous deposit, at first confused with the Corallian horizon, but which really belongs to the Kellaways Rock (*see* Table, p. 4), 350 to 500 feet lower in the stratigraphical sequence. This subdivision proved to be of very variable composition, generally including much sand or sandstone and some clay, but usually with some ferruginous bands. In the southern part of its underground range the deposit contains only a negligible quantity of iron, but towards its northern limits, in a belt traversed by the railway from Dover to Canterbury, it is richer and may locally contain beds of ore-quality. Its possible value as an ore, however, does not appear yet to have been tested, and the abundant admixture of glauconite and sandy matter which it generally contains may prevent its use. The iron occurs mainly in the oolitic form as in the Corallian ore, the brown grains or globules being set, in varying abundance, in a marly matrix. In a boring at Fredville, 8 miles N.W. of Dover, two ferruginous beds in the Kellaways Rock had each a thickness of about 14 feet; and at Chilton, 3 miles N.W. of Dover, two similar bands measured respectively 7 feet and 6 feet. Similar beds of less thickness were observed in borings at Maydensole and Bere Farm, while in some other borings the presence of the beds was indicated; but the evidence as to their quality and thickness was indefinite. The underground range of the formation is shown in 'Summary of Progress for 1916.' *Mem. Geol. Surv.*, p. 48.

Mr. E. O. Forster Brown informs us that the average analysis of a 5-ft. band passed through in the Bere Farm boring was as follows:—in the dry ore:—iron, 21·10 per cent.; lime, 17·00 per cent.; silica, 14·95 per cent.; sulphur, 0·87; in the calcined ore:—iron, 26·96 per cent.; silica, 19·10 per cent.; loss on calcination, 21·75 per cent.; moisture, 8·4 per cent.; sp. gravity of ore, about 2·88. The sandy beds of the Kellaways Rock below the ironstone band were found to contain from 14 to 19 per cent. of iron.

We are also indebted to Mr. E. O. Forster Brown for the following particulars of an analysis of a piece of core from the Kellaways

ironstone in the Fredville boring, collected by the Geological Survey. The specimen represented the most ferruginous-looking part of the band, and is likely to be considerably above the average:—

Stone dried at 100° *C.*

	Per cent.		Per cent.
Fe_2O_3	31·86	} = Iron ...	35·6
FeO	17·10		
SiO_2	17·42		
Al_2O_3	8·20		
MnO	·27		
CaO	4·58		
MgO	2·13		
P_2O_5	1·12	= Phosphorus	·503
Loss on heating (CO_2, H_2O, etc.)	17·50		
	100·18		

Other ferruginous bands were noticed among the *Lower Corallian* rocks in most of the borings which passed through this subdivision, as at Brabourne;[1] and in *Liassic* strata at Brabourne[2] and Elham; but all were too thin or poor to possess value.

Sussex and Kent. By G. W. Lamplugh.

Wealden Iron Ore.[3]

There is evidence that the extraction of iron from the Wealden ironstone was carried on at several places in the Weald by the Romans, and may have begun in pre-Roman times. The industry seems later to have fallen into abeyance, as there is no mention of ironworks in Sussex in Domesday Book. The earliest known documentary evidence with regard to it dates back to 1266, and afterwards occurs with increasing frequency up to the beginning of the 19th century. The industry appears to have reached its greatest productiveness during the 17th century, and to have declined rapidly during the 18th. The last flicker of its activity was the Ashburnham furnace in Sussex, which was in use until 1828. The decline is stated to have been due to the scarcity of fuel, not to the want of ore; and the final blow was given to the Wealden iron-trade by the introduction of pit-coal in the northern counties as a smelting fuel.

The ore most commonly used was the clay-ironstone occurring in nodules and thin beds in the lower part of the Wadhurst Clay, probably with the admixture of shelly calcareous ironstone from a slightly lower stratum. Traces of the old workings are numerous along the outcrop of this belt in East Sussex and Kent, but the ironstones dwindle westward, and are scantily represented in West

[1] *See* memoir *supra cit.*, p. 46.

[2] *Ibid.*, p. 50.

[3] The Geological Survey memoir on 'The Geology of the Weald' (1875) contains a chapter (xix., pp. 329–346) on the Ironworks of the Weald, giving many particulars of their history, etc., from which the present account is abstracted. Some farther information with analyses is contained in a 'Report . . . on the Prospects of Iron Mining and Smelting in the neighbourhood of Sheffield Park, Sussex,' by Prof. J. W. Gregory (*privately printed, Brighton*, 1908).

Sussex. On the Geological Survey One-inch map, Sheet 5, Old Series (published 1864), which covers the principal iron-district of the Weald, the spots where ironstone was observed are marked by a special symbol. These places are mainly in the neighbourhood of Buxted, Mayfield, Wadhurst, Burwash, and Waldron.

The ore was got by sinking shallow bell-pits near the outcrop. Several distinct stone-belts, mostly of nodules ('balls'), were recognised and named by the miners, but evidently showed much irregularity. There is no likelihood that the beds could be profitably worked under modern conditions. Few particulars as to the quality of the worked ore are on record, but that from Ashburnham is stated to have contained 35 per cent. of iron, or about the average percentage of the clay-ironstone of the Coal Measures.

A more recent attempt to re-work these ores by mining was made in the middle of last century at Snape Wood near Wadhurst, the ironstone at this place occurring in the Ashdown Sand, slightly below the Wadhurst Clay. The work was carried on for about a year (1857-1858), the ore being sent into Staffordshire. The ironstone was mined by levels and cross-cuts on both sides of the railway; on the north side, only one bed, 21 inches thick, was worked, and on the south side, two beds, of which the upper was in places 2 feet thick. The beds were irregular, thinning out at intervals. With reference to this working Prof. J. W. Gregory remarks (in the 'Report' above-cited):—"The ore contains only some 30 per cent. of iron, and the analysis [reprinted below] renders it easy to understand the failure of the attempt to mine the Snapewood deposit. From what could be seen on the surface, it is probable that the quantity of the ore was also too small for success." The analysis referred to, and that of another sample of clay-ironstone from near Ashburnham, are here reprinted from Prof. Gregory's Report, where they are accompanied by other analyses of the old furnace-slags, etc.

Analyses by Messrs. R. R. Tatlock & Thomson, 156, Bath Street, Glasgow, Jan. 15th, 1908, for Prof. J. W. Gregory.

	Clay Ironstone, Snape Wood.		Clay Ironstone, Gifford's Farm, near Ashburnham.
FeO	30·42	.....	42·08
Fe_2O_3	10·10	.....	6·85
FeS_2	·05	.....	·11
MnO	1·29	.....	2·32
CaO	·86	.....	3·87
MgO	·25	.....	1·76
Al_2O_3	8·24	.....	2·64
SiO_2	26·10	.....	6·46
SO_3	·06	.....	·20
P_2O_5	·49	.....	·65
TiO_2	·60	.....	·21
CO_2	20·25	.....	32·70
Combined Water H_2O	1·11	.....	Traces.
Moisture H_2O ...	·18	.....	·15
	100·00	.....	100·00

"It will be understood that the iron monoxide and the manganese, calcium and magnesium oxides . . . are combined with carbonic anhydride, to form carbonates."

LOWER GREENSAND.

Ferruginous sands are of common occurrence in the Lower Greensand of the south-eastern counties, but their iron-content is not high enough to have brought them into use as ores. Much of the iron is contained originally in the grains of the green mineral, glauconite, which is readily decomposed by weathering, so that the rocks containing it generally become rusty or ochreous at and for some distance below the surface. The iron set free is often partly segregated into thin streaks and veins of hard 'ironstone,' but this material, though frequently conspicuous at the surface, is generally too deficient both in quantity and quality to be of value. It appears to have been occasionally set aside and marketed where the containing sands have been dug for other purposes. Thus, in 'Mineral Statistics' for 1857, it is stated that "from Leighton Buzzard and its neighbourhood [where the sands have long been extensively dug] there appears to have been raised about 2,500 tons of Iron Ore" [during the year?]

In a few places the sands also contain iron in the form of separate granules and flakes of iron-oxide, scattered among the particles of quartz and other minerals that make up the bulk of the sand. In such cases, if the iron-grains could be separated from the rest, a useful ore might be obtained, but we are not aware that any process of this kind has yet been applied to these deposits. The ironsands of Kirby Underdale (p. 208) and Seend (p. 220) are of this type.

Another example occurs near Midhurst in Sussex, and was mentioned in the 'Geology of the Weald' (*Mem. Geol. Surv.*, 1875, p. 136) in the following terms:—"The dark-grained sand seen in the cutting at Petersfield is very peculiar. It occurs toward the lower part of the Sandgate Beds for some miles to the east and may be well seen in the railway cuttings south and south-west of Selham. It appears to be made up in great part of grains of ironstone. It occurs over the northern part of Cowdray Park, and can be seen along the road to Halfway Bridge; sometimes, as in the railway cutting just noticed, it consists chiefly of iron-grains, sometimes with these grains disseminated through a lighter sand." A further description of the deposit as it occurs east of Midhurst is given in a later memoir, 'The Geology of the Country near Chichester' (1903, p. 11).

This ironsand varies greatly, from place to place, in thickness and in the proportion of its iron-grains. It has been observed at intervals all round the western limits of the Weald, from the neighbourhood of Langley to Sheet and Petersfield, and thence to Midhurst; but its maximum thickness in this tract may be not more than 8 feet. East of Midhurst it expands, and may be traced for three miles to a little beyond Selham, but then disappears, being last seen in this direction below Barnett's Mill. Its outcrop covers most of Cowdray Park and has an area, east of Midhurst, of over 3 square miles. The thickness of the deposit in this area appears to be usually not less than 15 feet, and is much more in places, being over 30 feet in the railway cutting near Selham Station. The proportion of iron-grains in the sand is

highest in the southern portion of the outcrop. A sample collected by the Geological Survey in 1900 from an exposure in the south bank of the River Rother, at King John's Walk on the eastern outskirts of Midhurst, yielded on analysis:—iron 23 per cent., and insoluble matter 56·3 per cent.

We are indebted to Mr. E. O. Forster Brown for the following analysis of another sample which he took from an exposure north of the river at the east side of Cowdray Park:—Iron (metallic) 16 per cent.; insoluble gangue 70 per cent.; oxygen, and soluble in acid, and H_2O 14 per cent.; phosphorus, traces.

We are also informed by Mr. Forster Brown that tests of other parts of the northerly outcrop gave still poorer results. If the material should ever prove to be of economic value, it may be estimated that about 75,000,000 tons will be available in the exposed outcrop.

A similar sand with iron grains is mentioned in the Weald memoir (*Mem. Geol. Survey*, 1875, pp. 134, 337) as occurring near Albury in Surrey.

Hampshire and Kent. By G. W. Lamplugh.

TERTIARY.

The only part of England in which iron-ore has been obtained from Tertiary strata in modern times is the Hampshire coast, where an ore was extracted rather extensively from the Bracklesham beds of Eocene age at Hengistbury Head near Bournemouth, and, on a smaller scale, from somewhat newer (Oligocene) beds on the north-western shore of the Isle of Wight.

The Hengistbury ore is found in the form of large tabular concretions which occur in regular courses and range up to 12 feet or so in diameter. They have a reddish-brown exterior, but are grey within, and are made up of minute granules of iron carbonate (partly oxidised at the surface), mingled with fine angular quartz-particles, and generally including streaks and specks of lignite.

"Between 1847 and 1865 this concretionary iron-ore . . . was quarried on the northern and western sides of the headland, and also collected from the shore and the neighbouring reefs. The concretions, which contain about 30 per cent. of iron, were broken to a convenient size and shipped to South Wales and Staffordshire for smelting.[1] The profit on the quarried ore must have been meagre, for the extraction of the widely-spaced concretions entailed the removal of a disproportionately large amount of the surrounding clay, besides an overburden of sand and gravel; and work on the reefs had, it is said, to be stopped on account of the resulting increase in the rate of coast erosion."[2]

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[1] A. Tylor, 'On the Occurrence of Productive Iron Ore in . . . Hampshire' *Quart. Journ. Geol. Soc.*, vol. vi. 1850, pp. 133, 134, and G. H. West, *Brit. Assoc.*, Report for 1885, p. 427.

[2] 'Geology of the Country around Bournemouth.' 2nd ed. (*Mem. Geol. Surv.*), 1917, p. 71.

The annual volumes of 'Mineral Statistics' (*Mems. Geol. Surv.*) for the years from 1856 to 1865 inclusive, give a continuous output of ore from Hengistbury, aggregating 52,100 tons. The biggest annual output during these years was 13,000 tons for 1856, and the smallest, 1,400 tons for 1863.

In the same volumes there are, likewise, returns of a few hundred tons of iron-ore annually from the Isle of Wight, for the years 1858 to 1862 and 1864-5, aggregating 6,264 tons, with a maximum of 1,803 tons in 1859. A foot-note in the volume for 1863 (when no tonnage is given) states: "The Isle of Wight Iron Ores are obtained principally by dredging around the coast." In the Geological Survey memoir, 'The Geology of the Isle of Wight' (2nd ed., 1889, p. 252), it is mentioned that "the clay ironstone, which is found in considerable quantities lying loose upon the shore at the foot of the cliffs between Yarmouth and Hamstead ledge, was collected on the beach and sent to Swansea, to be smelted into iron."

A ferruginous bed at or near the base of the Oldhaven Beds, near Canterbury, is described in the memoir on 'The Geology of the London Basin,'[1] and is believed to have been used as an ore in past times.

[1] 'Memoirs of the Geological Survey,' vol. iv, 1872, pp. 266-270.

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